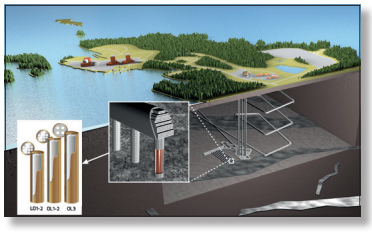
Radioactive Waste Management
2017

Sourcebook of International Activities Related to the Development of Safety Cases for Deep Geological Repositories



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Radioactive Waste Management

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NEA No. 7341

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NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 31 countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Russia, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission and the International Atomic Energy Agency also take part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally sound and economical use of nuclear energy for peaceful purposes;
- to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD analyses in areas such as energy and the sustainable development of low-carbon economies.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

Cover photos: The Onkalo spent nuclear fuel repository (Posiva); Yucca Mountain in Nevada (US Department of Energy).

Foreword

Since first introducing the modern concept of the "safety case", the OECD Nuclear Energy Agency (NEA) has continued to review international activities related to the development of safety cases for the deep geological disposal of radioactive waste. A large volume of documentation exists on the significant number of safety case projects that have been undertaken. This sourcebook attempts to document recent activities carried out by the NEA, the European Commission (EC) and the International Atomic Energy Agency (IAEA) for the operational and post-closure phases of geological repositories for radioactive waste that ranges from low-level waste to high-level waste and for spent fuel. While some overlap has been inevitable when setting the contexts and constraints of these research projects, work activities have more often complemented each other and enhanced the completeness of the topics being studied.

During its review of recent activities and the drafting of this sourcebook, the NEA noted a number of gaps in the documentation, as well as some key components of the safety case that could be considered in future work at the international level. Recent trends suggest that the NEA has tended to consolidate knowledge and experience gained internationally, whereas the IAEA has focused on producing guidance related to wider aspects of the safety case, and the EC has been guiding member states in establishing national safety policies and regulatory frameworks. All three organisations have also been engaged in activities that indirectly support safety case development. The NEA thermodynamics database, for example, provides input to safety calculations; various IAEA biosphere projects address safety case related issues; and the EC Project Performance Assessment Methodologies in Application to Guide the Development of the Safety Case (the Project PAMINA) examines assessment methodologies.

The specific objectives of this sourcebook are i) to document recent international activities conducted by the NEA, the EC and the IAEA in developing safety cases so as to help avoid duplication in work, ii) to assist in the dissemination of international publications on developing or integrating information for safety cases, and iii) to inform the NEA Integration Group for the Safety Case (IGSC) in designing its future programme of work.

Acknowledgments

The NEA would like to thank the European Commission (EC) and the International Atomic Energy Agency (IAEA) for providing information on their safety case activities and for their reviews of this sourcebook.

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List of abbreviations and acronyms

AMIGO	Safety Case for Deep Geological Disposal of Radioactive Waste (NEA project)
BELBaR	Bentonite Erosion: Effects on the Long Term Performance of the engineered Barrier and Radionuclide Transport (EC project)
BENIPA	Bentonite Barriers in Integrated Performance Assessment
BIOCLIM	Modelling Sequential Biosphere Systems under Climate Change for Radioactive Waste Disposal (EC project)
BIOMASS	Biosphere Modelling and Assessment (IAEA project)
BIOMOSA	Biosphere Modelling for Safety Assessments of Radioactive Waste Disposal (EC project)
BORIS	Building Confidence in Deep Disposal: The Borehole Injection Sites at Tomsk-7 and Krasnoyarsk-26 (EC project)
CARBOWASTE	Treatment and Disposal of Irradiated Graphite and Other Carbonaceous Waste (EC project)
CARD	Co-ordination of Research, Development and Demonstration Priorities and Strategies for Geological Disposal (EC project)
CAST	Carbon-14 Source Term (EC project)
CATCLAY	Process of Cation Migration in Clayrocks (EC project)
CATT	Co-operation and Technology Transfer on Long-term Radioactive Waste Management for Member States with Small Nuclear Programmes (EC project)
CIP	New Governance Approaches to Radioactive Waste Management in Europe: Cowam in Practice (EC project)
COBECOMA	State-of-the-art Document on the Corrosion Behaviour of Container Materials (EC project)
CONTAINER CORROSION	Long-term Performance of Candidate Materials for HLW/Spent Fuel Disposal Containers (EC project)
COWAM-2	Community Waste Management 2: Improving the Governance of Nuclear Waste Management and Disposal in Europe (EC project)
CROCK	Crystalline Rock Retention Processes (EC project)
DOPAS	Full Scale Demonstration of Plugs and Seals (EC project)
EBS	Engineered barrier system

EC	European Commission
ECOCLAY II	Effects of Cement on Clay Barrier Performance – Phase II (EC project)
EGOS	Expert Group on Operational Safety (NEA)
EMRAS	Environmental Modelling for Radiation Safety (EC project)
ENSREG	European Nuclear Safety Regulators Group
EPIC	Environmental Protection from Ionising Contaminants in the Arctic (EC project)
ERICA	Environmental Risk from Ionising Contaminants: Assessment and Management (EC project)
ESDRED	Engineering Studies and Demonstrations of Repository Designs (EC project)
Euratom	European Atomic Energy Community
FASSET	Framework for Assessment of Environmental Impact (EC project)
FEP	Features, events and processes
FIRST-NUCLIDES	Fast/Instant Release of Safety Relevant Radionuclides from Spent Nuclear Fuel (EC project)
FORGE	Fate of Repository Gases (EC project)
FSC	Forum on Stakeholder Confidence (NEA)
FUNMIG	Fundamental Processes of Radionuclide Migration (EC project)
GASNET	Gas Issues in Safety Assessment of Deep Repositories for Radioactive Waste (EC project)
GEOSAF	International Intercomparison and Harmonisation Project On Demonstrating the Safety of Geological Disposal (IAEA project)
GLAMOR	A Critical Evaluation of the Dissolution Mechanisms of High Level Nuclear Waste Glasses in Conditions of Relevance for Geological Disposal (EC project)
GLASTAB	Long-term Behaviour of Glass: Improving the Glass Term and Substantiating the Hypotheses (EC project)
HIDRA	Human Intrusion in the Context of Disposal of Radioactive Waste (IAEA project)
HUPA	Humic Substances in the Performance Assessment of Nuclear Waste Disposal: Actinide and Iodine Migration in the Far-Field
IAEA	International Atomic Energy Agency
IGD-TP	Implementing Geological Disposal – Technology Platform
IGSC	Integration Group for the Safety Case (NEA)
INSOTEC	International Socio-Technical Challenges for Implementing Geological Disposal (EC project)

INTESC	International Experiences in Safety Cases for Geological Repositories (NEA project)
IPPA	Implementing Public Participation Approaches in Radioactive Waste Disposal (EC project)
LABONET	International Network of Laboratories for Nuclear Waste Characterisation (IAEA)
LUCOEX	Large Underground Concept Experiments (EC project)
MeSA	Methods for Safety Assessment for Geological Disposal Facilities for Radioactive Waste (NEA project)
MICADO	Model Uncertainty for the Mechanism of Dissolution of Spent Fuel in a Nuclear Waste Repository (EC project)
MODARIA	Modelling and Data for Radiological Impact Assessments (IAEA project)
MoDeRn	Monitoring Developments for Safe Repository Operations and Staged Closure (EC project)
MODEX-REP	Elaboration of hydromechanical coupled models by interpretation of the disturbances observed during the sinking of the main shaft of an underground laboratory in Eastern France (EC project)
NANET	Network to Review Natural Analogue Studies and their Applications to Repository Safety Assessment and Public Communication (EC project)
NEA	Nuclear Energy Agency
NF-PRO	Understanding and Physical and Numerical Modelling of the Key Processes in the Near-Field and their Coupling for Different Host Rocks and Repository Strategies (EC project)
NUSSC	Nuclear Safety Standards Committee (IAEA)
OBRA	European Observatory for Long-term Governance on Radioactive Waste Management (EC project)
OECD	Organisation for Economic Co-operation and Development
PAAG	Performance Assessment Advisory Group (NEA)
PAMINA	Performance Assessment Methodologies in Application to Guide the Development of the Safety Case (EC project)
PEBS	Long-term Performance of Engineered Barrier Systems (EC project)
PETRUS II	Towards an European training market and professional qualification in Geological Disposal (EC project)
PETRUS III	Implementing Sustainable E&T Programmes in the Field of Radioactive Wastes Disposal (EC project)
PROTECT	Protection of the Environment from Ionising Radiation in a Regulatory Context (EC project)

R&R	Reversibility and Retrievability (NEA project)
RASSC	Radiation Safety Standards Committee (IAEA)
RECOSY	Redox Phenomena Controlling Systems (EC project)
RED-IMPACT	Impact of P and T and Waste Reduction Technologies on the Final Nuclear Waste Disposal (EC project)
REDUPP	Reducing Uncertainty in Performance Prediction (EC project)
REPMET	Radioactive Waste Repository Metadata Management Project (NEA)
RETROCK	Treatment of Geosphere Retention Phenomena in Safety Assessments (EC project)
RF	Regulators' Forum (NEA)
RK&M	Initiative on the Preservation of Records, Knowledge and Memory (NEA)
RWMC	Radioactive Waste Management Committee (NEA)
SAPIERR	Strategy Action Plan for Implementation of European Regional Repository (EC project)
SFCOMPO	Spent Fuel Isotopic Composition Database (NEA)
SITEX	Sustainable Network of Independent Technical Expertise for Radioactive Waste Disposal (EC project)
SKIN	Slow Processes in Close-to-equilibrium Conditions for Radionuclides in Water/Solid Systems of Relevance to Nuclear Waste Management (EC project)
SPIN	Safety and Performance Indicators (EC project)
THERESA	Coupled Thermal-hydrological-mechanical-chemical Processes for Application in Repository Safety Assessment (EC project)
TIMODAZ	Thermal Impact on the Damaged Zone Around a Radioactive Waste Disposal in Clay Host Rocks (EC project)
TRANCOM-II	Migration Case Study: Transport of Radionuclides in a Reducing Clay Sediment (EC project)
TRANSSC	Transport Safety Standards Committee (IAEA)
URF	Underground research facility
URL	Underground research laboratory
VAMP	Validation of Model Predictions (IAEA project)
VE	Ventilation Experiment in Opalinus Clay (EC project)
WASSC	Waste Safety Standards Committee (IAEA)

Chapter 1. Introduction

1.1. Background

All national radioactive waste management programmes today recognise that a robust safety case is essential in developing disposal facilities for radioactive waste. The modern concept of "safety case" was first introduced by the NEA Expert Group on Integrated Performance Assessment (IPAG) and has since been adopted internationally. Over the years, national programmes and international organisations have carried out a wide variety of activities related to improving the robustness of the safety case for radioactive waste geological disposal. In continuing the monitoring of major developments in safety cases, the NEA Integration Group for the Safety Case (IGSC) conducted a thorough review of the recent/ongoing safety case activities performed at the international level. This sourcebook summarises the activities undertaken by the NEA, the European Commission (EC) and the International Atomic Energy Agency (IAEA) relating to safety cases for the operational and post-closure phases of geological repositories for radioactive waste, ranging from low-level waste to high-level waste and spent fuel.

The objectives of the sourcebook are:

- to document the relevant international activities conducted by the three organisations in developing safety cases in order to avoid work duplications or redundancies;
- to assist in the dissemination of international publications on developing and integrating information for safety cases;
- to inform the IGSC in designing its future programme of work.

It is intended to update this document every two to three years for effective dissemination of the latest information on activities that have been undertaken relating to the safety case developments.

1.2. Organisation of this report

This report consists of five chapters: Chapter 1 describes the background and organisation of this sourcebook; Chapter 2 provides an overview of the current aims, organisation and activities of the three main international organisations, namely the NEA, the EC and the IAEA, working on safety cases for nuclear waste disposal. Chapter 3 provides an overview of the structure of the sourcebook, with a list of questions that were formulated to categorise the recent activities carried out by the three agencies. Chapter 4 provides the answers to this list of questions. Chapter 5 highlights areas where documentation is currently lacking. It should be noted that the focus of research and priorities varies, and thus the identified areas may only guide future work activities at the discretion of the organisation.

Links to reports on safety cases published by the NEA, EC and IAEA, are provided in Appendices A, B and C, respectively. These reports have either been published in the last 20 years or relate to projects currently underway. Where reports have been superseded, they are not included in the references, but a link to such reports is given for information.

Chapter 2. Overview

2.1. Nuclear Energy Agency

Within the NEA, safety cases are discussed within several fora, namely:

- The Radioactive Waste Management Committee (RWMC), which includes the:
  - Integration Group for the Safety Case (IGSC);
  - Forum on Stakeholder Confidence (FSC);
  - Regulators' Forum (RF).

International and joint research projects and initiatives, which include the following:

- Preservation of Records, Knowledge and Memory (RK&M) across Generations initiative;
- Reversibility and Retrievability (R&R);
- Predisposal Management of Radioactive Waste (EGPMRW);
- Thermochemical Database.

A more complete list of NEA documents relating to safety cases for the operational and post-closure phases of a geological disposal facility is given in Appendix A. NEA work in the area of geological disposal safety cases, undertaken by the aforementioned fora, is discussed below.

Radioactive Waste Management Committee

The NEA RWMC, created in 1975, is an international committee of senior representatives from regulatory authorities, radioactive waste management and decommissioning organisations, policymaking bodies and research and development institutions from NEA countries. The International Atomic Energy Agency (IAEA) participates in the work of the RWMC, and the European Commission (EC) is a full member of the committee. The RWMC maintains strong ties with national high-level advisory bodies to governments and with transnational bodies such as the International Commission on Radiological Protection (ICRP). Collaboration also takes place with the OECD Directorate for Public Governance and Territorial Development. The work undertaken by the RWMC is assisted by three working parties and their subgroups. Three of those parties and subgroups are discussed below. The RWMC also has a Working Party on the Management of Materials from Decommissioning and Dismantling (WPDD), but the remit of that group falls outside the scope of this current document; it is discussed in more detail in NEA (2013b).

Integration Group for the Safety Case

The IGSC was established in 2000 by the RWMC in recognition of the need to foster full integration of all aspects of the safety case. The IGSC is the main technical advisory body to the RWMC on deep geological disposal, especially for long-lived and high-level radioactive waste. Its mandate includes the exploration and substantiation of the scientific and technical aspects of repository development, and of safety cases to build and demonstrate confidence in repository safety. The IGSC provides a neutral forum for

experts to interact and communicate, while activities undertaken by the IGSC are intended to help foster consensus on best practices and advance the development of innovative approaches used in all stages of repository implementation. Activities are organised in the following thematic framework:

- scientific basis;
- safety assessment strategy and tools;
- repository design and implementation;
- safety case integration and management.

The IGSC has published reports on various areas, for example on the nature and purpose of the post-closure safety cases for geological repositories, indicators in the safety case, underground research laboratories and methods for safety assessment of geological disposal facilities for radioactive waste. Recent IGSC publications can be downloaded free from the NEA website at www.oecd-nea.org/rwm/igsc.

With the emergence in the past decades of the safety case concept applied in the development of disposal repositories, the IGSC has enhanced understanding in this area and has been discussing the convergence of the safety concept through projects such as International Experiences in Safety Cases for Geological Repositories project (INTESC); Methods for Safety Assessment for Geological Disposal Facilities for Radioactive Waste (MeSA); Approaches and Challenges for the use of Geological Information in the Safety Case for Deep Geological Disposal of Radioactive Waste (AMIGO), the Joint EC/NEA Engineered Barrier System project, the NEA International Features, Events and Processes (FEP) database, the various scientific bodies of the IGSC such as the Clay Club, the Salt Club and other related work activities. The group regularly organises international events to reveal and share information on the development of safety cases. In 2013, the IGSC held its 2nd international safety case symposium to discuss the latest knowledge, as well as the challenges faced by various stakeholders, such as waste management organisations, regulatory authorities or research institutes, in developing and/or refining safety cases throughout the development lifecycles of radioactive waste disposal facilities.

To stay abreast of the state-of-the-art knowledge and technologies in safe radioactive waste management, the IGSC participates in international projects and work activities. Examples of international projects include, but are not limited to the EC Fate of Repository Gases (FORGE) project, the EC Monitoring Development for Safe Repository Operation and Staged Closure (MoDeRn) project and the EC Implementing Geological Disposal of Radioactive Waste Technology Platform (IGD-TP).

As some national radioactive waste management programmes are approaching their licensing phases, the IGSC particularly needs to address issues emerging in such advanced programmes. To this end, in 2012, the NEA Regulators' Forum (RF) co-organised a joint workshop with the IGSC "Preparing for Construction and Operation of Geological Repositories – Challenges to the Regulator and the Implementer" and subsequently created a new Expert Group on Operational Safety (EGOS) in 2013. The aim of the EGOS is to share technical, regulatory and other stakeholders experience in operational safety. More specifically, the EGOS group has the following aims and objectives:

- to identify and evaluate plausible hazards in a geological repository, using experience gained from the operation of mines (both uranium and non-radioactive), nuclear facilities and relevant engineering projects from outside the nuclear industry;
- to mitigate potential human errors;
- to share and improve know-how on the practical assessment of hazards;
- to define best practices and technical solutions for risk prevention and mitigation;

- to enable the NEA, via the IGSC, to foster in-depth exchanges with other international organisations/projects in the field of operational safety.

Technical workshops on managing fire risks in operating geological repositories and potential issues relevant to the design and operation of the ventilation systems have been organised in late 2013 and 2014. An interim report on fire risk management was issued in 2015. The expert group also conducted a survey in 2014 to reveal the potential "co-activity" hazards (that is hazards associated with both construction and waste emplacement activities). An analysis report analysing the various types of operational hazards and their preventative/mitigation strategies and measures was also published in 2015. Current ongoing work initiatives of the EGOS include i) develop an NEA operational safety hazard database for geological repositories; ii) issue guidance on developing waste acceptance criteria for geological repositories; and iii) issue guidance on transportation and emplacement of HLW or SF. It is intended that this expert group will maintain strong connections with the design and implementation of geological repositories. The IGSC recognises the importance of balancing operational safety and long-term repository safety (as noted in previous meetings) and will continue to further evaluate the issue in its ongoing work activities.

Forum on Stakeholder Confidence

The Forum on Stakeholder Confidence (FSC) was set up in 2000, to facilitate the sharing of experience in addressing the societal dimension of radioactive waste management. It explores means of ensuring an effective dialogue with the public with a view to strengthening confidence in the decision-making processes. As the nature of exchanges between waste management organisations, regulators and the wider population have evolved to include a variety of stakeholders at national, regional and local levels, this forum has helped contribute to such trends. The FSC hosts regular meetings where stakeholders can express their views during the processes by which they are involved in radioactive waste management governance.

The operations of this forum reach into all aspects of repository development, from the siting and development of the waste disposal facilities through to the longer-term management of the system, as well as the development of safety cases.

Regulators' Forum

The Regulators' Forum (RF) of the RWMC is made up of regulators who participate in the work of the NEA RWMC. Their key focuses include, but are not limited to, the facilitation of multilateral communication and information exchange between RWMC regulators through open dialogues among peers; as well as defining and addressing future regulatory challenges and issues in the area of waste management and disposal. Many workshops have been held by the RF since the 1990s. In 2012, a joint workshop was held by the IGSC and the RF to discuss the challenges faced by implementers and regulators in preparing for their licence applications and licence reviews. More details of the group and its publications can be found at www.oecd-nea.org/rwm/regulator-forum.html.

International projects and joint research initiatives

The NEA RWMC has six international projects and joint research programmes, of which the following four address issues of relevance to certain aspects of safety cases.

Preservation of Records, Knowledge and Memory across Generations initiative, 2011-ongoing

Once a waste repository is closed, there remains a need for indirect oversight of the site, including monitoring, maintaining records of the site, applying safeguards according to active international agreements, and maintaining a memory of the facility. The NEA RK&M recognised that there is a strong cultural dimension relating to the design and

implementation of the institutional arrangements required to preserve the records, knowledge and memory, and so instigated an initiative in this area in 2011. To assist member countries to strategically preserve crucial records and knowledge, the RK&M initiative is developing a menu-driven document, RK&M wiki, which will allow key elements and criteria of the preservation of records and knowledge. Several reports, including a literature review on markers and memory preservation for deep geological repositories, have been produced, and a conference was held on this subject in Verdun in September 2014.

The RK&M initiative recognises the challenges of managing large amount of data for a long period of time in national radioactive waste management programmes. Associated with the RK&M initiative is a project specifically initiated to evaluate the issues of Radioactive Waste Repository MetaData Management (RepMet). Its main aim is to create sets of metadata that can be used by national programmes to manage their repository data, information and records in a way that is both harmonised internationally and suitable for long-term management and utilisation for example in safety case development.

Reversibility and Retrievability project, 2007-2011

In 2007, the NEA RWMC established a project to study R&R issues in the geological disposal of radioactive wastes. This project was supported by contributions from member states. Participants from 15 countries, from the IAEA and the EC, and from other RWMC groups (the FSC, the IGSC and the RF) contributed to the initiative. This project comprised several phases: compilation of a bibliography of references on R&R topics (in 2010), a questionnaire to establish the current status of disposal programmes with respect to R&R in the member countries (reported in 2010), with a final report published in 2011 entitled "Reversibility and Retrievability for the Deep Disposal of High-Level Radioactive Waste and Spent Fuel" (NEA, 2011).

This project has a direct connection with the design and implementation of repositories.

Sorption project, 1997-2012

This project was launched in 1997 to study the potential of chemical thermodynamic models for improving the representation of sorption phenomena in the long-term safety analysis of radioactive waste repositories. Sorption is one of the most important processes with regard to the retardation of migration of radionuclides in a repository towards the biosphere. Well characterised datasets relating to a range of minerals and soils were considered in a benchmarking exercise that allowed a number of aspects of sorption models to be tested, e.g. single and complex mineral systems, ranges of chemical conditions. The project produced three reports, namely, i) Sorption Project Phase I Status Report on *Using Thermodynamic Sorption Models for Guiding Radioelement Distribution Coefficient (Kd) Investigations* (NEA, 2001); ii) Phase II Report on *Interpretation and Prediction of Radionuclide Sorption onto Substrates Relevant for Radioactive Waste Disposal Using Thermodynamic Sorption Models* (NEA, 2005); and iii) Phase III Report on *Thermodynamic Sorption Modelling in Support of Radioactive Waste Disposal Safety Cases* (NEA, 2012).

Data provided by the project are used to inform and parameterise the calculations undertaken in support of the scientific basis of the safety case.

Thermochemical Database project, 1984-ongoing

The purpose of the NEA Thermochemical Database project is to make available a comprehensive, internally consistent, quality-assured and internationally recognised chemical thermodynamic database of selected chemical elements in order to meet the specialised modelling requirements for safety assessments of radioactive waste disposal systems. Initial focus was given to certain actinides (U, Am, Np and Pu) and Tc, but the

database now covers many more elements (Ni, Se, Zr, Th, Sn, Fe and Mo), and also cement minerals and high ionic strength solutions.

As with the Sorption project, such data is used to inform and parameterise the calculations undertaken in support of the scientific basis of the safety case.

2.2. European Commission

European Commission directives

The following EC directives have been issued in the past 20 years relating directly or indirectly to safety case issues for geological disposal:

- Council Directive 2011/70/Euratom of 19 July 2011 establishing a community framework for the responsible and safe management of spent fuel and radioactive waste.
- Council Directive 2014/87/Euratom amending 2009/71/Euratom by further bolstering the framework for the safety of nuclear installations in the EU.
- Council Directive 2006/117/Euratom of 20 November 2006 on the supervision and control of shipments of radioactive waste and spent fuel.
- Council Directive 2013/59/Euratom specifies basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealed Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom, and 2003/122/Euratom to cover various specific safety aspects in normal and emergency situations to protect the health of workers and the general public from ionising radiation, as well as on the control of high-activity sealed radioactive sources and orphan sources.
- Commission Recommendation 1999/669/EC, Euratom on waste classifications for solid radioactive waste.
- Commission Recommendation of 24 October 2006 on the management of financial resources for the decommissioning of nuclear installations, spent fuel and radioactive waste (2006/851/Euratom).
- Directive 2011/70/Euratom establishes a community framework to ensure responsible and safe management of spent fuel and radioactive waste by member states, stating the obligations and suggested measures in order to manage the waste and spent fuel safely and responsibly.

A list of EC directives and documentation related to safety case development along with their hyperlinks is shown in Appendix B.

European Nuclear Safety Regulators Group

The European Nuclear Safety Regulators Group (ENSREG) was set up by Commission Decision 2007/530/Euratom to contribute to the achievement of the community objectives in the field of spent fuel and radioactive waste management. The conclusions and recommendations of ENSREG were reflected in the Council Resolution of 16 December 2008 on Spent Fuel and Radioactive Waste Management, and the Council Conclusions of 10 November 2009 on the report by the ENSREG. More information about this group and the safety case relevant work that they undertake is available from its website.

In 2014, the EC instigated a joint initiative between the Directorate General for Energy (DG-ENER) and the Joint Research Centre (JRC) to promote public participation in implementing energy policies. The "Energy – Transparency Centre of Knowledge" (E-TRACK) uses a web platform to collect and disseminate knowledge and practices in the

implementation of public participation in radioactive waste management, allowing stakeholders to learn from each other, share lessons learnt and exchange information on complex aspects. Key activities are described in their 2014 report.

European Commission actions funded under Euratom Framework Programmes

The research and training actions carried out as part of the European Atomic Energy Community (Euratom) programmes are managed by two services (directorates general or DGs) of the European Commission: i) the EC Joint Research Centre, created under the Euratom Treaty as an in-house science service and ii) the DG Research and Innovation, responsible for research in nuclear energy. There are two different types of actions:

- Direct research actions – performed within the institutes of the EC Joint Research Centre.
- Indirect research actions – funded by the EU, in the form of projects carried out in the member states' research organisations. Those projects are either cost shared collaborative research and development projects (defined as research and innovation actions in Horizon 2020) or co-ordination and support actions for co-ordinating or supporting activities such as training, access to infrastructure, pilot studies, each with full funding from the EU.

Since 1975, all projects and direct actions that have been funded in the successive Euratom Programmes in the field of radioactive waste management and disposal are contributing to various extents to the safety case. The relevant indirect action projects in the Framework Programmes 5, 6 and 7 are respectively listed in Tables 2.1, 2.2 and 2.3. The current Euratom research and training programme (2014-2018) is defined as complementing the overall European Commission Horizon 2020 Framework Programme for research and innovation. These Indirect Action Horizon 2020 projects are not listed, nor discussed.

The Direct Action projects, i.e. those performed within the JRC, the 7th Framework Programme (FP7) and at the onset of Horizon 2020 are listed in Table 2.4. FP7 activities are groups of individual projects conducted under the listed umbrellas.

The EC funded projects cover aspects primarily relating to the scientific basis of the safety case, though projects covering other aspects of the safety case are also covered, e.g. implementation of a nuclear waste disposal system, stakeholder engagement in nuclear disposal programmes, performance assessment methodologies.

Table 2.1. Safety case relevant projects funded under the Euratom Framework Programme 5 (1998-2002)

Project acronym	Project name	Dates
BENIPA	Bentonite Barriers in Integrated Performance Assessment	2000-2003
BIOCLIM	Modelling Sequential Biosphere Systems under Climate Change for Radioactive Waste Disposal	2000-2003
BIOMoSA	Biosphere Modelling for Safety Assessments of Radioactive Waste Disposal	2000-2003
BORIS	Building Confidence in Deep Disposal: The Borehole Injection Sites at Tomsk-7 and Krasnoyarsk-26	2000-2003
COBECOMA	State-of-the-art Document on the Corrosion Behaviour of Container Materials	2001-2003
CONTAINER CORROSION	Long-term Performance of Candidate Materials for HLW/Spent Fuel Disposal Containers	2000-2004
ECOCLAY II	Effects of Cement on Clay Barrier Performance – Phase II	2000-2003
EPIC	Environmental Protection from Ionising Contaminants in the Arctic	2000-2003
FASSET	Framework for Assessment of Environmental Impact	2000-2003
GASNET	Gas Issues in Safety Assessment of Deep Repositories for Radioactive Waste	2001-2004
GLAMOR	A Critical Evaluation of the Dissolution Mechanisms of High Level Nuclear Waste Glasses in Conditions of Relevance for Geological Disposal	2001-2004
GLASTAB	Long-term Behaviour of Glass: Improving the Glass Term and Substantiating the Hypotheses	2000-2003
HUPA	Humic Substances in the Performance Assessment of Nuclear Waste Disposal: Actinide and Iodine Migration in the Far-Field	2001-2004
MODEX-REP	Elaboration of Hydro-mechanical Coupled Models by Interpretation of the Disturbances Observed during the Sinking of the Main Shaft of an Underground Laboratory in Eastern France	2000-2003
NANET	Network to Review Natural Analogue Studies and their Applications to Repository Safety Assessment and Public Communication	2003-2004
RETROCK	Treatment of Geosphere Retention Phenomena in Safety Assessments	2001-2004
SPIN	Safety Performance Indicators	2000-2003
TRANCOM-II	Migration Case Study: Transport of Radionuclides in a Reducing Clay Sediment	2000-2003
- - -	The Role of Monitoring in a Phased Approach to Geological Disposal of Radioactive Waste	2000-2004

Table 2.2. Safety case relevant projects funded under the Euratom Framework Programme 6 (2002-2006)

Project acronym	Project name	Dates
CARD	Co-ordination of Research, Development and Demonstration Priorities and Strategies for Geological Disposal	2006-2008
CATT	Co-operation and Technology Transfer on Long-term Radioactive Waste Management for Member States with Small nuclear Programmes	2006-2007
CIP	New Governance Approaches to Radioactive Waste Management in Europe: Cowam in Practice	2007-2009
COWAM-2	Community Waste Management 2 : Improving the Governance of Nuclear Waste Management and Disposal in Europe	2004-2006
ERICA	Environmental Risk from Ionising Contaminants: Assessment and Management	2004-2007
ESDRED	Engineering Studies and Demonstrations of Repository Designs	2004-2009
FUNMIG	Fundamental Processes of Radionuclide Migration	2005-2008
MICADO	Model Uncertainty for the Mechanism of Dissolution of Spent Fuel in a Nuclear Waste Repository	2006-2009
NF-PRO	Understanding and Physical and Numerical Modelling of the Key Processes in the Near-Field and their Coupling for Different Host Rocks and Repository Strategies	2004-2007
OBRA	European Observatory for Long-term Governance on Radioactive Waste Management	2006-2008
PAMINA	Performance Assessment Methodologies in Application to Guide the Development of the Safety Case	2006-2009
PROTECT	Protection of the Environment from Ionising Radiation in a Regulatory Context	2006-2008
RED-IMPACT	Impact of P and T and Waste Reduction Technologies on the Final Nuclear Waste Disposal	2004-2007
SAPIERR	Strategy Action Plan for Implementation of European Regional Repository	2003-2005
SAPIERR-2	Strategy Action Plan for Implementation of European Regional Repository – Stage 2	2006-2009
THERESA	Coupled Thermal-hydrological-mechanical-chemical Processes for Application in Repository Safety Assessment	2007-2009
TIMODAZ	Thermal Impact on the Damaged Zone Around a Radioactive Waste Disposal in Clay Host Rocks	2006-2010

Table 2.3. Safety Case relevant projects funded under the Euratom Framework Programme 7 (2007-2013)

Project acronym	Project name	Dates
BELBaR	Bentonite Erosion: Effects on the Long Term Performance of the Engineered Barrier and Radionuclide Transport	2012-2016
CARBOWASTE	Treatment and Disposal of Irradiated Graphite and other Carbonaceous Waste	2008-2013
CAST	Carbon-14 Source Term	2013-2018
CATCLAY	Process of Cation Migration in Clayrocks	2010-2014
CROCK	Crystalline Rock Retention Processes	2011-2013
DOPAS	Full Scale Demonstration of Plugs and Seals	2012-2016
FIRST-NUCLIDES	Fast/Instant Release of Safety Relevant Radionuclides from Spent Nuclear Fuel	2012-2014
FORGE	Fate of Repository Gases	2009-2013
INSOTEC	International Socio-Technical Challenges for Implementing Geological Disposal	2011-2014
IPPA	Implementing Public Participation Approaches in Radioactive Waste Disposal	2011-2013
LUCOEX	Large Underground Concept Experiments	2011-2014
MoDeRn	Monitoring Developments for Safe Repository Operation and Staged Closure	2009-2013
PEBS	Long-term performance of Engineered Barrier Systems	2010-2014
PETRUS II	Towards an European Training Market and Professional Qualification in Geological Disposal	2009-2012
PETRUS III	Implementing Sustainable E&T Programmes in the Field of Radioactive Wastes Disposal	2013-2016
RECOSY	Redox Phenomena Controlling Systems	2008-2011
REDUPP	Reducing Uncertainty in Performance Prediction	2011-2014
SITEX	Sustainable Network of Independent Technical Expertise for Radioactive Waste Disposal	2012-2013
SKIN	Slow Processes in Close-to-equilibrium Conditions for Radionuclides in Water/Solid Systems of Relevance to Nuclear Waste Management	2011-2013

Table 2.4. Safety case relevant research activities conducted under the indirect action, i.e. performed by the EC Joint Research Centre, for FP7 and the onset of Horizon 2020

Project acronym	Project name
Euratom Framework Programme 7 (2007-2013)	
SAFEWASTE	Waste Package and Systems for Transport, Storage and Disposal of High-level Nuclear Waste and Spent Fuel
NWD/NWD2	Nuclear Waste Disposal/ Nuclear Waste Disposal and Decommissioning
ND MINWASTE	Nuclear Data for Radioactive Waste Management and Safety of New Reactor Developments
Horizon 2020	
CEBAMA	Cement Based Materials, Properties, Evolution, Barrier Functions
EFWAS	Evolution of Fuels and Waste Forms in Storage and Disposal Conditions
JOPRAD	Towards Joint Programming on Radioactive Waste Disposal
MIND	Development of the Safety Case Knowledge Base about the Influence of Microbial Processes on Geological Disposal of Radioactive Wastes
MISSLaNS	Modular Interface and Surface Science Laboratory for Nuclear Safety
Modern2020	Development and Demonstration of Monitoring Strategies and Technologies for Geological Disposal
SPAM	Spent Fuel Alteration Mechanisms under Long-term Storage
StoS	Spent Nuclear Fuel Storage Studies – Phase A
CONWISA	Corrosion of Nuclear Waste under Intermediate Storage and Accident Conditions

Implementing Geological Disposal Technology Platform

The Implementing Geological Disposal Technology Platform (IGD-TP) is a scientific and technical forum, which focuses on the operation of geological repositories for high-level nuclear waste in Europe. It was established under the EC auspices in November 2009, following a feasibility study undertaken in 2006-2007 (EC Co-ordination Action on Research, Development and Demonstration Priorities and Strategies for Geological Disposal [CARD] project). The IGD-TP issued a Vision Document stating that "by 2025 the first geological disposal facilities for spent fuel, high-level waste, and other long-lived radioactive waste will be operating safely in Europe" (EC, 2009). In line with this vision, the objectives, main priorities and activities of IGD-TP, as defined in its Strategic Research Agenda and Deployment Plan (2011-2016), are to initiate and carry out European strategic initiatives to facilitate the stepwise implementation of safe, deep geological disposal of spent fuel, high-level waste, and other long-lived radioactive waste by solving the scientific, technological and social challenges, and to support the waste management programmes in member states. Although IGD-TP started as an EC platform, organisations from outside of the EC are also participants.[1] The current Strategic Research Agenda (SRA) includes the following key topics:

- safety case;

1. Nuclear Waste Management Organization (NWMO), Canada; Radioactive Waste Management Funding and Research Center (RWMC), Japan; Vinca Institute of Nuclear Sciences, Serbia; Institute of Environmental Geochemistry NAS and MES of Ukraine, Ukraine.

- waste forms and their behaviour;
- technical feasibility and long-term performance of repository components;
- development strategy of the repository;
- safety of construction and operations;
- monitoring;
- governance and stakeholder involvement.

A large number of projects, which have been funded by the Euratom 7th Framework Programme, were in direct support to IGD-TP priorities.

2.3. International Atomic Energy Agency

The IAEA Safety Standards

By statute, the IAEA is authorised "to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialised agencies concerned, standards of safety for protection of health and minimisation of danger to life and property (including such standards for labour conditions), and to provide for the application of these standards to its own operation, as well as to the operations making use of materials, services, equipment, facilities, and information made available by the Agency…"

The Commission on Safety Standards (CSS) oversees the IAEA safety standards programme while the IAEA Secretariat of four safety standard committees manages the preparation and review of the safety standards. The four safety standard committees, composed of nominated participants from the member states, are: i) the Nuclear Safety Standards Committee (NUSSC); ii) the Radiation Safety Standards Committee (RASSC); iii) the Waste Safety Standards Committee (WASSC); and iv) the Transport Safety Standards Committee (TRANSSC).

In developing a safety standard, all member states are consulted. As such, safety standards may be considered as resulting from the international consensus of member states.

Particularly related to safe management of radioactive waste, the WASSC is a standing body of senior experts that provides advice on the overall programme for the development, review and revision of standards relating to radioactive waste safety, i.e. waste management, waste treatment and safety of disposal facilities and decommissioning. The key objective of WASSC is to achieve consensus, quality, coherence and consistency in the development of international standards for radioactive waste safety.

Safety standards in relation to safety cases and safety assessments

The IAEA has a long-standing comprehensive programme of work on safety cases and has published a number of safety standards and technical reports on various aspects of the safety case and stages of the waste disposal programme. The main safety standards related to safe radioactive waste management include:

Safety Fundamentals:
- Fundamental Safety Principles (SF-1), [2006];

Safety Requirements:
- Safety Assessment for Facilities and Activities (GSR Part 4), [2009];

Specific Safety Requirements:

- Disposal of Radioactive Waste: Specific Safety Requirements (SSR-5), [2011];
- Regulations for the Safe Transport of Radioactive Material (SSR-6), [2012];

Safety Guide:

- The Management System for the Disposal of Radioactive Waste (GSG-3.4), [2008];
- The Classification of Radioactive Waste (GSG-1), [2009];
- The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste (GSG-13), [2013];

Specific Safety Guide:

- The Safety Case and Safety Assessment for the Disposal of Radioactive Waste: Specific Safety Guide (SSG-23), [2012];
- Geological Disposal Facilities for Radioactive Waste (SSG-14), [2011]-superseded Safety Guide WS-G-1.1, 1999;
- Borehole Disposal Facilities for Radioactive Waste (SSG-1), [2009];
- Near Surface Disposal for Radioactive Waste (SSG-29), [2014].

The IAEA Safety Standards and IAEA publications can be downloaded from www-ns.iaea.org/standards/default.asp?s=11&l=90 and www-pub.iaea.org/books.

Nuclear safety and security: Special projects

International inter-comparison and harmonisation projects are one of the mechanisms used by the IAEA for examining the application and use of its safety standards, with a view to ensuring their effectiveness and working towards harmonisation of approaches to the safety of radioactive waste management. Below is a summary of geological safety case relevant projects that have been undertaken in the past 20 years.

International Inter-comparison and Harmonisation Project on Demonstrating the Safety of Geological Disposal (GEOSAF and GEOSAF II)

The International Inter-comparison and Harmonisation Project on Demonstrating the Safety of Geological Disposal (GEOSAF) ran from 2008 to 2011, with the aim of working towards harmonisation in approaches to demonstrating the safety of geological disposal and a special emphasis on the expectations from the regulatory authorities engaged in the licensing process with respect to the development of the safety case.

On the request of the participants to the initial project, a follow-up project commenced in 2012. This second phase, GEOSAF II, has the objective to reach a joint understanding and work towards harmonisation of views and expectations regarding the safety of the operational phase for geological disposal of radioactive waste with regards to post-closure safety. More specifically, the approach taken in GEOSAF Part II is to address operational safety for geological disposal working on the development and review of an overall safety case that integrates both operational and post-closure aspects.

Further information on GEOSAF projects can be found at www-ns.iaea.org/projects/geosaf.

Biosphere research (VAMP, BIOMASS, EMRAS, EMRAS II and MODARIA)

The IAEA has undertaken a number of projects in the field of biosphere assessment over the past 20 years. These projects have included consideration of the data and scientific understanding underpinning both conceptual and mathematical biosphere assessment models, and the definition of biosphere systems and scenario definition. Human and non-human biota have both been regarded as the end point of the assessment, and in some instances comparisons have been made between models, and where possible, models and experimental or field data. This work has served to further underpin the scientific basis of the safety case in the biosphere, and also the assessment strategy and tools used in the biosphere part of the safety case.

Further latest details of these projects are available at:

- www-ns.iaea.org/projects/emras/emras2;
- www-ns.iaea.org/projects/modaria.

Human Intrusion in the Context of Disposal of Radioactive Waste

In 2012, the IAEA held a technical meeting to discuss "Human Intrusion and Future Human Actions in relation to Disposal of Radioactive Waste". The objective of the meeting was to explore a means of effectively addressing future human actions and human intrusion in the safety case and safety assessment of radioactive waste disposal facilities, including both geological and near-surface disposal facilities.

The discussions focused on issues such as the difference and commonality of human intrusion scenarios for geological and near-surface disposal facilities. Three groups were established to address specific issues related to technical, social and design aspects. As a result of these discussions, a new international project was launched: "HIDRA – Human Intrusion in the Context of Disposal of Radioactive Waste". This two-year project commenced in 2013 and aims to provide guidance on how to address human actions in the safety case and the safety assessment of radioactive waste disposal in the future. These assessments will then be used to optimise siting, design and waste acceptance criteria within the context of a safety case.

Further details of this project are available on the IAEA website: www-ns.iaea.org/projects/hidra.

Peer reviews

The IAEA offers member states expert review services related to the peaceful uses of nuclear science and technology. Over the years, the IAEA had conducted numerous independent peer reviews and developed expertise in specific areas. In the field of radioactive waste management, the IAEA has developed an integrated review service for radioactive waste and spent fuel management, decommissioning and remediation programmes – ARTEMIS. ARTEMIS aims to improve organisational performance and to contribute to increased national and international confidence in their activities. The Integrated Regulatory Review Service (IRRS) of the IAEA is designed to strengthen the effectiveness of the national regulatory infrastructure of member states for nuclear, radiation, radioactive waste and transport safety and security of radioactive sources while recognising the ultimate responsibility of the member states.

Chapter 3. Structure of the safety case sourcebook

This source book is structured to follow the four main themes of the Integration Group for the Safety Case (IGSC) activities[1], namely:

- safety assessment strategy and tools;
- repository design and implementation;
- scientific basis;
- safety case integration and management.

3.1. Background to the questions asked with respect to each theme

Assessment strategy and tools (Section 4.1)

In Section 4.1, consideration is given to strategies and tools that have been developed, or are under development, with respect to safety cases. This includes the development of strategies to frame the safety case, which relates to both the implementation and management of the safety case, tools for use to assist in defining the system, and in identifying potential release scenarios for consideration in the safety case, and tools for use to undertake performance assessment calculations in support of the safety case. Consideration as to the manner in which quality assurance is handled in terms of the data used, and broader knowledge management systems which encompass data, models and staff is provided under the "integration and management" theme (Section 4.4).

Design and implementation of repositories (Section 4.2)

In Section 4.2, consideration is given to work that has been, or is currently being, undertaken with respect to the design and implementation of geological repositories. The focus will be on geological repository construction, waste emplacement (strategies, techniques) and engineered barrier systems (EBS).

Scientific basis (Section 4.3)

Consideration is given in this section to the various aspects of the safety case that have been and/or are currently under scientific investigation to support assumptions, both conceptual and numerical, within a safety case. The following areas are covered: waste inventory and waste forms; system characterisation and evolution; and contaminant release and transport processes. Geological repository construction, waste emplacement and the short- to medium-term performance of the EBS are considered under the theme "design and implementation of repositories" (Section 4.2). Methods for handling uncertainties associated with the conceptual/numerical understanding of any aspect of the system are covered under the "integration and management" theme (Section 4.4).

1. www.oecd-nea.org/rwm/igsc.

Integration and management (Section 4.4)

In this theme, consideration is given to wider aspects of the safety case. Topics covered here include handling uncertainties in the safety case, building confidence in the safety case, quality assurance, knowledge management and stakeholder involvement.

3.2. Summary of the questions

The sources of operational and post-closure safety case information relating to geological disposal are arranged according to the four main themes of the IGSC, as described above. The questions have been formulated such that they allow readers to find publications concerning key safety case related issues.

1. Assessment strategy and tools
    a. What structures are used to frame the safety case?
    b. What tools are there to assist in system descriptions and conceptual model development?
    c. What tools and strategies for scenario development are employed?
    d. What monitoring programmes are recommended with respect to the staged disposal process (construction, operation, staged closure and post-closure)?
2. Design and implementation of repositories
    a. What research is being undertaken with respect to potential inventories for disposal?
    b. What recommendations are there with respect to site screening and selection?
    c. What research is being undertaken with respect to geological disposal facility design; construction?
    d. What role do underground research laboratories (URLs) have in the design and implementation of repositories?
    e. What research is being undertaken with respect to waste package design for use in long-term disposal?
    f. What research is being undertaken with respect to engineered barrier systems, i.e. waste form, disposal containers/overpacks, buffer and backfill materials that surround the containers and backfill plugs and seals in shafts/tunnels/galleries/emplacement rooms?
    g. What research is being undertaken with respect to waste transfer, transport and emplacement?
    h. What consideration is given to shielding and criticality?
    i. What are the disposal concepts with respect to retrievability?
    j. What is the international position on workers and their safety during the construction and operation of a geological repository, and what other potential exposure groups are considered?
3. Scientific basis
    a. What research is being undertaken with respect to the source term associated with specific radionuclides and/or waste forms? What release processes have been investigated?

b. What investigations are underway with respect to the management of particular waste forms or materials that might be emplaced in a geological repository?

c. What research is there into processes, coupled or otherwise, that might occur in the near field and/or geosphere? Near field may be defined as the excavated area of a repository near or in contact with the waste packages whose characteristics can be altered by the repository or its content. Please list research on the evolution of buffer and backfill materials, plugs and seals used in backfilling underground tunnels/galleries/waste emplacement cells/rooms.

d. What transport processes in the near field have been investigated?

e. What geologies have been and are being studied? Are there specific issues relating to these geologies which have required special consideration?

f. What transport processes in the geosphere have been investigated?

g. What research is being undertaken with respect to biosphere representation, transport within the biosphere, and biosphere evolution, for safety cases?

h. What laboratories are there which can provide supporting evidence for aspects of the scientific basis of the safety case?

4. Integration and management

a. How are safety cases documented?

b. What is optimisation and how is it demonstrated?

c. How are uncertainties (future, models and data) dealt with or recommended to be handled?

d. How is the iterative nature of safety cases managed?

e. What quality and knowledge management systems are in place for safety cases?

f. What training programmes are there to ensure both capacity and knowledge are retained over the timescales relevant to a repository lifecycle?

g. What measures are recommended to build confidence in the safety case?

h. What are the current recommendations with respect to stakeholder involvement?

i. What recommendations relate to the regulatory review process?

Chapter 4. Detailed safety case sourcebook

4.1. Assessment strategy and tools

4.1.a. What structures are used to frame the safety case?

NEA	• (2008-2010) The Integration Group for the Safety Case (IGSC) undertook a review of safety assessment approaches in the Methods for Safety Assessment for Geological Disposal Facilities for Radioactive Waste (MeSA) project. • In 2013, the NEA issued an updated version of the Safety Case Brochure.
EC	• (2006-2009) The EC 6th Euratom Performance Assessment Methodologies in Application to Guide the Development of the Safety Case (PAMINA) framework project. The project focused on how to improve and harmonise methodologies and tools for demonstrating the safety of deep geological disposal of long-lived radioactive waste including spent fuel in various geological environments. PAMINA produced a report on *Trial of Formal Use of Expert Judgement for Scenario Conceptualisation*. • (2005-2008) The EC 6th Euratom Fundamental Processes of Radionuclide Migration (FUNMIG) framework project aimed to develop a fundamental understanding of radionuclide migration processes in the geosphere, the application to performance assessment for different host-rock types, and communication of the results. The project issued their final scientific and technical report in 2009.
IAEA	• (2009) The IAEA produced as part of its General Safety Requirements series a report titled *Safety Assessment for Facilities and Activities* (GSR-4). This includes sections on basis of and the graded approach to the safety assessment.

4.1.b. What tools are there to assist in site descriptions and conceptual model development?

NEA	• (2012) The NEA IGSC published a report on "Indicators in the Safety Case" (NEA/RWM/R(2012)7). • (2002) The NEA hosted a workshop in October 2000 on safety performance indicators, subsequently publishing the proceedings "Safety Performance Indicators – Workshop Proceedings" (NEA/CSNI/R(2002)2).
EC	• The EC held Euradwaste 2013 in Lithuania to review recent EC activities in radwaste management, specifically to discuss key challenges in geological disposal and to review the current state-of-the-art knowledge, research, development and demonstration, policy, strategic, legislative and socio-political aspects. • (2006-2009) The EC 6th Euratom Performance Assessment Methodologies in Application to Guide the Development of the Safety Case (PAMINA) framework project produced a report on "Trial of formal Use of Expert Judgement for Scenario Conceptualisation". • (2000-2002) The EC 5th Euratom Testing of Safety and Performance Indicators (SPIN) framework project evaluated a number of safety and performance indicators based on performance assessment for disposal of radioactive waste in granite formations.
IAEA	• (2005-2010) In 2005, the IAEA set up a co-ordinated research project on "The Use of Numerical Models in Support of Site Characterization and Performance Assessment Studies of Geological Repositories". The objectives of this project were: demonstration of the use of modelling strategies to address relevant issues using site-specific data (if available); to gain insights in the reliability and uncertainty of numerical model predictions; and to improve the modelling capabilities at institutions in the participating member states. The final report of this project was published in 2013 (TECDOC-1717). • (2003) The IAEA Working Group on Principles and Criteria for Radioactive Waste Disposal subsequently updated and revised TECDOC-767, publishing a report on *Safety Indicators for the Safety Assessment of Radioactive Waste Disposal* (TECDOC-1372). • (1999-2003) The IAEA undertook a co-ordinated research project into "Natural activity concentrations and fluxes as indicators for the safety assessment of radioactive waste disposal". • (1994) The IAEA Working Group on Principles and Criteria for Radioactive Waste Disposal, set up in 1991, published a report on *Safety Indicators in Different Time Frames for the Safety Assessment of Underground Radioactive Waste Repositories* (TECDOC-767).

4.1.c. What tools and strategies for scenario development are employed?

NEA	• (2000) The NEA Radioactive Waste Management Committee (RWMC) previously had a PAAG, which in the mid-1980s established a working group on the identification and selection of scenarios for the performance assessment of radioactive waste repositories. This culminated in a FEP database relevant to post-closure safety of repositories for solid radioactive waste, published in 2000. The 2000 database is also available on CD-ROM. In 2013, the IGSC revealed the latest approach used to develop scenarios in different national programmes. In 2015, The NEA held its 2nd workshop on scenario development in June 2015. This workshop revealed the latest scenario development strategies and methods used in various national programmes since 1999. Proceedings of this workshop was published in March 2016. • (2006-ongoing) The NEA International Features, Events and Processes (FEP) database was updated in 2006, and is currently undergoing further updates, and also a reimplementation to an online format. • (2001) The NEA Performance Assessment Advisory Group (PAAG) reviewed scenario description methodologies that had been used up until 1990*, and later scenario methodologies and assessments developed since 1990 were reviewed and discussed at a workshop held in Madrid in 1999. Key outcomes of the workshop are documented in a 2001 NEA report.
EC	• (2006-2009) The EC 6th Euratom Performance Assessment Methodologies in Application to Guide the Development of the Safety Case (PAMINA) framework project produced many reports relating to scenario development: definition and assessment of scenarios; scenario uncertainty; quantifying scenario probability; trial of formal use of expert judgement for scenario conceptualisation; and scenario development.
IAEA	• The IAEA identified and evaluated stylised human intrusion scenarios, in addition to a method to modify the stylised scenarios in supporting the development of the Human Intrusion in the Context of Disposal of Radioactive Waste report.

* NEA (1992), *Safety Assessment of Radioactive Waste Repositories: Systematic Approaches to Scenario Development*, OECD, Paris.

4.1.d. What monitoring programmes are recommended with respect to the staged disposal process (construction, operation, staged closure and post-closure)?

NEA	• (Ongoing) Monitoring is considered within the NEA by two working parties within the RWMC. The RWMC initiative "Preservation of Records, Knowledge, and Memory (RK&M) across generations" considers monitoring, by the nature of the activities undertaken, to serve such a role automatically. The RWMC's Forum on Stakeholder Confidence considers the role of monitoring to support the needs and expectations of local communities, building a sustainable relationship between the facility and its hosts. A survey of local communities' expectations and demands on monitoring of geological disposal facilities was undertaken in 2012; the results can be obtained at the NEA website. The NEA organised a joint NEA/IAEA workshop on operational safety in June 2016, to reveal the latest findings of the IGSC Expert Group on Operational Safety (EGOS) and the IAEA International Inter-comparison and Harmonisation Project on Demonstrating the Safety of Geological Disposal (GEOSAF) projects, monitoring was further evaluated in this workshop. • In 2014, the NEA RK&M published a report on "Preservation of Records, Knowledge and Memory across Generation – Monitoring of Geological Disposal Facilities: Technical and Societal Aspects".
EC	• (2009-2013) The 7th framework EC funded project Monitoring Developments for Safe Repository Operations and Staged Closure (MoDeRn) aims at providing a reference framework for the development and possible implementation of monitoring activities and associated stakeholder engagement during relevant phases of the radioactive waste disposal process, i.e. during site characterisation, construction, operation and staged closure, as well as a post-closure institutional control phase. More information and results of this project can be obtained from the project website. • Further to the outcomes of the MoDeRn project and the IGD-TP 4th Exchange Forum, Modern2020 is to provide the means for developing and implementing an effective and efficient repository operational monitoring programme, that will be driven by safety case needs, while taking into account the requirements of specific national contexts such as waste inventory, hose rocks, repository concepts and regulations. • (2004) The EC established a "Thematic network on the role of monitoring in a phased approach to geological disposal of radioactive waste". A final report was published in 2004.
IAEA	• (2014) An IAEA Safety Guide SSG-31: *Monitoring and Surveillance of Radioactive Waste Disposal Facilities* provides recommendations and guidance on how to plan and perform monitoring and surveillance programmes for disposal facilities for radioactive waste. Also included are recommendations on how to use results from the monitoring and surveillance of radioactive waste disposal facilities over their entire lifetime. • The Safety Guide covers both man-made and naturally occurring radioactive materials, superseding TECDOC-1208 and two safety reports relating to residues from the mining and milling of uranium and thorium and also near-surface disposal facilities* (IAEA DS357). • (2005) The IAEA gave consideration to a wider range of waste forms in *Environmental and Source Monitoring for Purposes of Radiation Protection* (IAEA Safety Guide, RS-G-1.8). • (2001) The IAEA reviewed the role of "monitoring with respect to the geological disposal for high-level waste", considering all stages of disposal from site exploration through to post-closure (TECDOC-1208).

* Safety Reports Series No. 27 (2002) and No. 35 (2004).

4.2. Design and implementation of repositories

4.2.a. What activity or research is being undertaken with respect to potential inventories for disposal?

NEA	• (2015) The NEA RWMC approved the creation of an expert group to evaluate the issue of predisposal management of radioactive waste. • (2014) The NEA created an expert group in 2014, under the auspices of the RWMC to develop a methodology which facilitates comparison of national radioactive waste inventory data. In 2015, the Expert Group on Waste Inventorying and Reporting Methodology (EGIRM) developed a method which focuses on spent fuel and conditioned radioactive waste. The method was then tested by nine countries and is currently being refined. The group plans to modify this method in 2017-2018 to cover other radioactive waste types. • (2001-ongoing) The NEA has an online Spent Fuel Isotopic Composition Database (SFCOMPO). It was originally developed at the JAERI Department of Fuel Cycle Safety Research's Fuel Cycle Safety Evaluation Laboratory in the 1990s, but was transferred to the NEA Data Bank after December 2001. SFCOMPO provides isotopic composition data via the internet, archiving measured isotopic composition data and the values of their ratios, which are required for the validation of burn-up codes.
EC	• (Ongoing) The EC publishes situation reports to present the status concerning waste generation, inventories and disposal capacities in the EU member states.
IAEA	• (2011-ongoing) In 2011, the IAEA established an "International Network of Laboratories for Nuclear Waste Characterisation" (LABONET), to increase efficiency in sharing international experience in the application of proven, quality-assured practices for the characterisation of low- and intermediate-level radioactive waste and waste packages and to accelerate risk reduction and clean-up of the environmental legacy. • (2009) As part of its Nuclear Energy Series, the IAEA published a report on *Determination and Use of Scaling Factors for Waste Characterization in Nuclear Power Plants* (NW-T-1.18).

4.2.b. What recommendations are there with respect to site screening and selection?

NEA	• N/A
EC	• Council Directive 2011/70/Euratom on establishing a community framework for the responsible and safe management of spent fuel and radioactive waste. • Council Directive 2013/59/Euratom which states basic safety standards for protection against the dangers arising from exposure to ionising radiation.
IAEA	• (2011) In the IAEA Specific Safety Requirements *Disposal of Radioactive Waste* (SSR-5), requirement 15 relates specifically the site characterisation for a disposal facility. • (2011) The IAEA Specific Safety Guide *Geological Disposal Facilities for Radioactive Waste* (SSG-14) provides guidance relating to site characterisation, which includes the site selection stage (paragraphs 6.4 to 6.24).

4.2.c. What research is being undertaken with respect to geological disposal facility design and construction?

NEA	• (2014) The NEA IGSC created an expert group to address potential operational challenges – EGOS in 2013. The expert group recognises fire risk management is one of the major challenges in operating underground facilities and formed a stand-alone task group to address all issues related to fire risk management. Workshops relating to fire risk and ventilation design have been held in. More information can be found at www.oecd-nea.org/rwm/egos. • Further workshops are also foreseen in 2014-2015. • (2003) The NEA and EC jointly held a workshop on "Engineered Barrier System (EBS): Design Requirements and Constraints". The workshop proceedings were published in 2004 and are available from the NEA website: The IGSC published a flyer in 2012.
EC	• (2012-ongoing) The EC IGD-TP Full Scale Demonstration of Plugs and Seals (DOPAS) project studies the plugging and sealing systems for geological repositories. • (2001-2004) The EC 5th Euratom Ventilation Experiment in Opalinus Clay (VE) framework project aimed to evaluate in situ the consequences of desaturation in consolidated clay formations. A final report has been issued. • Joint workshop with the NEA on "Engineered Barrier System (EBS)" in 2003. • The EC Engineering Studies and Demonstration of Repository Designs (ESDRED) have been ongoing for over three decades to study the feasibility of different underground activities such as disposal cell/drift outfitting, waste canister transportation from surface and emplacement of waste in the disposal cell/drift.

IAEA	• (2011) The IAEA has produced a report on *The Management System for the Development of Disposal Facilities for Radioactive Waste* (NW-T-1.2). Section 4 of that report concerns the application of a management system to the repository design and development, outlining the design process and how each aspect can be appropriately managed. • (2011) In the IAEA Specific Safety Requirements *Disposal of Radioactive Waste* (SSR-5), requirements 16 and 17 relate specifically the design and construction of a disposal facility. • (2011) The IAEA Specific Safety Guide *Geological Disposal Facilities for Radioactive Waste* (SSG-14) provides guidance relating to the design, waste acceptance and construction of a disposal facility (paragraphs 6.25 to 6.46). • (2009) The IAEA Safety Specific Guide *Borehole Disposal Facilities for Radioactive Waste* (SSG-1) aims to provide guidance on the design, construction, operation and closure of borehole disposal facilities for the disposal of radioactive waste in accordance with the relevant safety requirements.

4.2.d. What role do underground research laboratories (URLs) have in the design and implementation of repositories?

NEA	• (2013) The NEA RWMC has since built upon that work, integrating more recent URL literature and the strategic outlook of NEA member countries on URLs. The report is available from the NEA website. • (2001) The NEA RWMC published a report about what URLs are, the different types, locations, the research and development carried out, and their value to national programmes. It also considered questions to ask when deciding to construct a URL, and the opportunities and benefits of international co-operation in URLs. The report is available from the NEA website.
EC	• (2012-2016) The EC 7th Euratom Full Scale Demonstration of Plugs and Seals (DOPAS) framework project aims to improve the adequacy and consistency regarding industrial feasibility of plugs and seals, the measurement of their characteristics, the control of their behaviour over time in repository conditions and also their hydraulic performance acceptable with respect to the safety objectives. Five different demonstration experiments (using URLs) are part of the project, taking place in the Czech Republic, Finland, France, Germany and Sweden. • (2011-2014) The EC 7th Euratom Large Underground Concept Experiments (LUCOEX) framework project has the overall objective to demonstrate technical feasibility in situ for safe and reliable construction, manufacturing, disposal and sealing of repositories for long-lived high-level nuclear waste. Consideration has been given to four repository concepts and a further four technical issues*. More information, and project reports, can be found at the project website.
IAEA	• (2004-ongoing) Under the auspices of the IAEA, nationally developed underground research facilities (URFs) and associated laboratories concerned with the geological disposal of radioactive waste have been offered for use by various member states since 2004. The URFs and laboratories form a network for training in and demonstration of waste disposal technologies and the sharing of knowledge.

* Gallery construction, manufacturing and emplacement of buffer around waste canisters, emplacement of waste packages, and backfilling and sealing of galleries.

4.2.e. What research is being undertaken with respect to waste package design for use in long-term disposal?

NEA	• N/A
EC	• (2000-2004) The EC 5th Euratom Long-term Performance of Candidate Materials for HLW/Spent Fuel Disposal Containers (CONTAINER CORROSION) framework project sought to address the qualification of corrosion resistant materials for long-lived HLW/spent fuel disposal containers. The final report is available from the Cordis website. • (2001-2003) The EC 5th Euratom State-of-the-art document on the Corrosion Behaviour of Container Materials (COBECOMA) framework project undertook a review of container corrosion literature produced in national and international programmes in the preceding 15-20 years.
IAEA	• (2011-ongoing) The IAEA has established a working group for the dual use cask for spent fuel. The primary objective of the group is to develop guidance for the structure and content of an integrated safety case for a dual purpose cask. More information about the group is available from the IAEA website: www-ns.iaea.org/tech-areas/waste-safety/spent-fuel-casks-wg.asp. • (2009) The IAEA produced a report on *Geological Disposal of Radioactive Waste: Technological Implications for Retrievability* (Report No. NW-T-1.19). This includes a section on implications of retrievability on the design of the waste containers and emplacement cells. • (2000) The IAEA produced technical guidance on the *Inspection and Verification of Waste Packages for Near Surface Disposal* (TECDOC-1129).

4.2.f. What research is being undertaken with respect to engineered barrier systems?

NEA	• (2012) The NEA IGSC organised a workshop on "Cementitious Materials in Safety Cases for Geological Repositories for Radioactive Waste: Role, Evolution and Interactions". The workshop proceedings are available from the NEA website.
EC	• (2012-2016) The EC 7th Euratom Full Scale Demonstration of Plugs and Seals (DOPAS) framework project aims to improve the adequacy and consistency regarding industrial feasibility of plugs and seals, the measurement of their characteristics, the control of their behaviour over time in repository conditions and also their hydraulic performance acceptable with respect to the safety objectives. • (2000-2003) The Bentonite Barriers in Integrated Performance Assessment (BENIPA) assessed the state-of-the-art in the treatment of bentonite barriers in integrated performance assessment, evaluating the consistency of methods and data available to justify the capability of bentonite barriers in fulfilling their safety functions. Relevant design concepts for bentonite barriers were reviewed. A project handbook covering safety assessment details of the bentonite barriers was developed.
IAEA	• N/A

Note: Additional projects relating to engineered barrier systems and the near field are discussed in Section 4.3.

4.2.g. What research is being undertaken with respect to waste transfer, transport and emplacement?

NEA	• N/A
EC	• (2004-2009) The EC 6th Euratom Engineering Studies and Demonstrations of Repository Designs (ESDRED) framework project had the overall objective to demonstrate the technical feasibility at an industrial scale for activities carried out to construct, operate and close a deep geological repository, and at the same time comply with requirements on long-term safely, operational safety, retrievability and monitoring. The project had four themes: buffer construction technology; waste canister transfer and emplacement technology; heavy load emplacement technology; and low pH cement for shotcrete and sealing plug construction technology.

IAEA	• (2002-2012) The IAEA has been producing regulations and advisory material relating to the safe transport of radioactive material, as part of its safety standards series, for a number of years*. These reports can be accessed via the IAEA website:
	  • (2014) The IAEA has recently published a supplement to the IAEA Safety Standard Series GS-G-1.5, which related to the regulatory control of radiation sources, *Model Regulations for the Use of Radiation Sources and for the Management of the Associated Radioactive Waste* (TECDOC-1732).
	  • (In preparation) The IAEA is currently preparing an update to the *Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material* (TS-G-1.1), originally published in 2002 and last updated in 2008 (DPP425).
	  • (In preparation) The IAEA is currently preparing an update to the *Planning and Preparing for Response to Transport Events Involving Radioactive Material* (TS-G-1.2), originally published in 2002 (DPP469).

* TS-G-1.1 (2002, updated in 2008), TS-G-1.2 (2002), TS-G-1.3 (2007), TS-G-1.4 (2008) TS-G-1.5 (2009), TS-R-1 (2005, 2009), SSR-6 (2012).

4.2.h. What consideration is given to shielding and criticality?

NEA	• N/A
EC	• N/A
IAEA	• (In preparation) The IAEA is currently preparing a safety guide on *Criticality Safety for Facilities and Activities Handling Fissionable Material* (DPP407). More information on the planned update can be accessed via the IAEA website.

4.2.i. *What are the disposal concepts with respect to retrievability?*

NEA	• (2007-2011) The NEA Reversibility and Retrievability (R&R) project aimed to bring together technical experts and political decision makers to discuss and better understand the capability of retrieving waste emplace in geological repositories. Major milestones in the project were: a bibliographic review, a survey of NEA member countries' positions, and discussions within an ever increasing group of interested parties to refine a leaflet on current international understanding of R&R.
EC	• (2004) The EC established a "Thematic Network on the Role of Monitoring in a Phased Approach to Geological Disposal of Radioactive Waste". In the final report of from this network, the role of monitoring with respect to retrievability was discussed. • (2000) The EC instigated a concerted action to provide a forum for experts from organisations involved in the development of national disposal concepts for long-lived radioactive waste in nine European countries to establish a clear interpretation and working definition of radioactive waste retrievability from deep repositories and to compare the approaches adopted in the different countries. Results are documented in a project report.
IAEA	• (2009) The IAEA produced a report on *Geological Disposal of Radioactive Waste: Technological Implications for Retrievability* (Report No. NW-T-1.19).

4.2.j. *What is the international position on workers and their safety during the construction and operation of a geological repository, and what other potential exposure groups are considered?*

NEA	• 2014) The NEA IGSC EGOS has a task group on fire risk. A workshop relating to fire risk and ventilation design was held in February 2014.
EC	• (1996) The EC Directive 2013/59 laid down basic safety standards for protection against the dangers arising from exposure to ionising radiation. The new Directive repealed several directives e.g. Directives 96/29/Euratom which covered "basic safety standards for the protection of the health of worker and the general public against the dangers arising from ionizing radiation".

IAEA	• (In preparation) The IAEA is currently preparing a safety guide which will revise existing guidance on Occupational Radiation Protection, based on the revised Basic Safety Standards (BSS), and bring all the relevant safety guides on protection of workers into a single comprehensive safety guide on occupational radiation protection. As such it will, when published, supersede those occupational exposure safety guides published in 1999 and also RS-G-1.6 and GS-G-3.2*. More information on the planned safety guide can be accessed via the IAEA website.
	• (2008-2011) The IAEA International Project on Demonstrating the Safety of Geological Disposal (GEOSAF) project produced a companion report on operational safety.
	• (1999) The IAEA produced a series of safety guides relating to occupational exposures: *Occupational Radiation Protection (RS-G-1.1); Assessment of Occupational Exposure Due to Intakes of Radionuclides (RS-G-1.2);* and *Assessment of Occupational Exposure Due to External Sources of Radiation (RS-G-1.3).* These reports are available at:
	  • www-pub.iaea.org/MTCD/publications/PDF/Pub1081_web.pdf;
	  • www-pub.iaea.org/MTCD/publications/PDF/P077_scr.pdf;
	  • www-pub.iaea.org/mtcd/publications/pdf/pub1076_web.pdf.

* RS-G-1.6: Occupational Radiation Protection in the Mining and Processing of Raw Materials (2004). GS-G-3.2: The Management System for Technical Services in Radiation Safety (2008).

4.3. Scientific basis

4.3.a. What research is being undertaken with respect to the source term associated with specific radionuclides and/or waste forms? What release processes have been investigated?

Spent fuel and high-level waste

NEA	• N/A
EC	• (2012-2014) The EC 7th Euratom Fast/Instant Release of Safety Relevant Radionuclides from Spent Nuclear Fuel (FIRST-NUCLIDES) framework project has the overall objective to provide for improved understanding of the fast/instantly released radionuclides from disposed high burn-up UO_2 spent nuclear fuel. This issue is given a high priority in the Strategic Research Agenda of the IGD-TP. • (2011-2014) The EC 7th Euratom Reducing Uncertainty in Performance Prediction (REDUPP) framework project aims to investigate how surfaces of solids with a fluorite structure change with time during dissolution. Laboratory experiments are performed to monitor dissolution of CaF_2, CeO_2, ThO_2 and UO_2, in connection with ab initio calculations. Another aspect of the project involves investigating if using natural groundwater in the leaching tests has an effect on the measured dissolution rate of UO_2. Reports and project newsletters are available from the Swedish Nuclear Fuel and Waste Management Company (SKB) website: www.skb.se/lagerbladet_31780.aspx. • (2006-2009) The EC 6th Euratom Model Uncertainty for the Mechanism of Dissolution of Spent Fuel in a Nuclear Waste Repository (MICADO) framework project aimed to assess the uncertainties in models describing the dissolution mechanism of spent nuclear fuel in a repository for geological time periods. • (2001-2004) The EC 5th Euratom Critical Evaluation of the Dissolution Mechanisms of High Level Nuclear Waste Glasses in Conditions of Relevance for Geological Disposal (GLAMOR) framework project aimed to achieve a common understanding on why there is considerable decrease with time of the dissolution rate of high-level waste glass upon contact with geological disposal media. The final report of the project is available from the Cordis website. • (2000-2003) The EC 5th Euratom Long-term Behaviour of Glass: Improving the Glass Term and Substantiating the Hypotheses (GLASTAB) framework project aimed to increase the confidence in glass source term modelling for representative geological disposal conditions (crystalline and clay rocks). The project final report is available from the Cordis website.
IAEA	• N/A

Other waste forms

NEA	• N/A
EC	• (2013-2018) The EC 7th Euratom Carbon-14 Source Term (CAST) framework project aims to develop understanding of the generation and release of 14C from radioactive waste materials under conditions relevant to waste packaging and disposal to underground geological disposal facilities. The project will focus on releases from irradiated metals (steels, Zircaloys) and from ion-exchange materials as dissolved and gaseous species. A study to consider the current state-of-the-art knowledge with regards to 14C release from irradiated graphite will also be undertaken, to further our knowledge from existing projects in this area i.e. CARBOWASTE. At present there is no project-specific website, but further information on the project can be found on the Cordis website: http://cordis.europa.eu/projects/rcn/110253_en.html.
IAEA	• (2011-ongoing) In 2011 the IAEA established an International Network of Laboratories for Nuclear Waste Characterisation (LABONET), to increase efficiency in sharing international experience in the application of proven, quality-assured practices for the characterisation of low- and intermediate-level radioactive waste and waste packages and to accelerate risk reduction and clean-up of the environmental legacy.

4.3.b. What investigations are underway with respect to particular waste forms or materials that might be emplaced in a deep geological repository?

NEA	• N/A
EC	• (2008-2013) The EC 7th Euratom Treatment and Disposal of Irradiated Graphite and other Carbonaceous Waste (CARBOWASTE) framework project aims to develop an integrated waste management approach for irradiated graphite and other carbonaceous waste, which are mainly characterised as intermediate-level radioactive waste. Methodologies and databases will be developed for assessing different technology options*, and the feasibility of the associated processes will be experimentally investigated to deliver data for modelling the microstructure and localisation of contaminants. • (2004-2007) The EC 6th Euratom Impact of P and T and Waste Reduction Technologies on the Final Nuclear Waste Disposal (RED-IMPACT) framework project aimed to assess the effects of reduction nuclear waste generation and partitioning and transmutation expressed in technical terms of the benefits and disadvantages for waste management and geological disposal. In particular the source term contained on each waste stream, including all secondary wastes, of characteristic nuclear fuel cycle concepts will be assessed.
IAEA	• (2012) The IAEA published a TECDOC on *Review of Sealed Source Designs and Manufacturing Techniques Affecting Disused Source Management* (TECDOC-1690). This report notes that increasing attention is being given to using borehole disposal facilities for such materials, referencing IAEA SSG-1. • (2011-ongoing) In 2011 the IAEA established an "International Network of Laboratories for Nuclear Waste Characterisation" (LABONET), to increase efficiency in sharing international experience in the application of proven, quality-assured practices for the characterisation of low- and intermediate-level radioactive waste and waste packages and to accelerate risk reduction and clean-up of the environmental legacy. • (2010) The IAEA published a TECDOC on *Progress in Radioactive Graphite Waste Management* (TECDOC-1647). • (2006) The IAEA produced a TECDOC on *Characterization, Treatment and Conditioning of Radioactive Graphite from Decommissioning of Nuclear Reactors* (TECDOC-1521). • (2004) In IAEA TRS-427, "Predisposal Management of Organic Radioactive Waste", consideration is given to the properties and performance of the conditioned waste forms and the requirements for disposal.

* These include direct disposal in adopted waste containers, treatment and purification before disposal or even recycling for reuse in the nuclear field.

4.3.c. What research is there into processes, coupled or otherwise, that might occur in the near field and/or geosphere?

NEA	• (1984-Ongoing) The NEA Thermochemical Database project aims to make available a comprehensive, internally consistent, quality-assured and internationally recognised chemical thermodynamic database of selected chemical elements in order to meet the specialised modelling requirements for safety assessments of radioactive waste disposal systems. • The IGSC discussed long-term gas behaviours in geological repositories in its 2011 topical session. A position paper was issued in 2015 – "Relevance of Gases in the Post-Closure Safety Case for Radioactive Waste".
EC	• (2008-2011) The EC 7th Euratom Redox Phenomena Controlling Systems (RECOSY) framework project aimed to develop a sound understanding of redox phenomena controlling the long-term release/retention of radionuclides in nuclear waste disposal and providing tools to apply the results to performance assessment/safety case. • (2006-2010) The EC 6th Euratom Thermal Impact on the Damaged Zone Around a Radioactive Waste Disposal in Clay Host Rocks (TIMODAZ) framework project studied the combined effect of the excavation disturbed zone and the thermal impact on the clay host rocks around a radioactive waste disposal. Three types of clay were investigated: the Boom Clay, the Opalinus Clay and the Callovo-Oxfordian argilitte. Even if the characteristics of these clays are different, the thermo-hydro-mechanical processes governing the fracturing and the sealing present some similarities. • (2007-2009) The EC 6th Euratom Coupled Thermal-hydrological-mechanical-chemical Processes for Application in Repository Safety Assessment (THERESA) framework project aimed to develop a scientific methodology for evaluating the capabilities of mathematical models and computer codes used in performance assessment and applied to the design, construction, operation, performance and safety assessment, and post-closure monitoring of geological nuclear waste repositories, based on the scientific principles governing coupled thermo-hydro-mechanical and chemical processes in geological systems and geo-materials. Although no website is available, publications associated with this project can be found on the internet. For example, the proceedings of a conference held jointly with the TIMODAZ project can be found at the following website: http://bookshop.europa.eu/en/impact-of-thermo-hydro-mechanical-chemical-thmc-processes-on-the-safety-of-underground-radioactive-waste-repositories-pbKINA25527. • (2004-2007) The EC 6th Euratom Understanding and Physical and Numerical Modelling of the Key Processes in the Near-Field and their Coupling for Different Host Rocks and Repository Strategies (NF-PRO) framework project investigated dominant processes and process couplings affecting the isolation of nuclear waste within the near-field and apply and develop conceptual and mathematical models for predicting the source-term release of radio nuclides from the near-field to the far-field. The project final report can be found at the following website.

EC	• (2000-2003) The EC 5th Euratom Thematic Network on Gas Issues in Safety Assessment of Deep Repositories for Radioactive Waste (GASNET) framework project produced a report on the "Treatment in Safety Assessments of Issues Arising from Gas Generation". • (2000-2003) The EC 5th Euratom Effects of Cement on Clay Barrier Performance – Phase II (ECOCLAY II) framework project worked on many aspects related to cement degradation, clay alteration and performance assessment, to compare their results, to discuss them and finally to propose an assessment on the effects of an alkaline plume on clay properties. The final report was published in 2005. • (1997-1999) The EC Effects of Cement on Clay Barrier Performance (ECOCLAY) project had the main objectives to investigate the interaction and possible mineral alteration of clay barriers (bentonite) in contact with cement, and to define the type of cement which produces a pH environment compatible with clay mineral stability, thus minimising the impact on the clay barriers. The final report from the project was published in 2000. • (2001-2004) The EC 5th Euratom Humic Substances in the Performance Assessment of Nuclear Waste Disposal: Actinide and Iodine Migration in the Far-Field (HUPA) framework project aimed at developing understanding for the impact of humic substances on the colloidal transport of Actinides and Iodine in the aquatic far-filed, including tools for application to the PA. • The last project report is available online. • (2005-2008) The EC 6th Euratom Fundamental Processes of Radionuclide Migration (FUNMIG) framework project aimed to develop a fundamental understanding of radionuclide migration processes in the geosphere, the application to performance assessment and communication of the results. It deals with coupled transport phenomena in the geosphere for crystalline, clay and salt host-rock repositories. The final scientific and technical report of the project is available.
IAEA	• (2003) Numerous near-field components and processes (the groundwater environment, waste forms, container materials, backfill materials, construction materials, mobilisation of radionuclides and gas production and its consequences) were discussed in the IAEA technical report on the *Scientific and Technical Basis for the Geological Disposal of Radioactive Wastes* (TRS-413). The report is available from the IAEA website: www-pub.iaea.org/MTCD/Publications/PDF/TRS413_web.pdf.

4.3.d. What transport processes in the near field have been investigated?

NEA	• (1997-ongoing) The NEA Sorption project was launched in 1997 with the objective to study the potential of chemical thermodynamic models for improving representation of sorption phenomena in the long-term safety analysis of radioactive waste repositories.
EC	• (2013-2016) The EC 7th Euratom Bentonite Erosion: Effects on the Long term Performance of the Engineered Barrier and Radionuclide Transport (BELBaR) framework project aims to increase the knowledge of the processes that controls clay colloid stability, generation and ability to transport radionuclides. • (2012-2016) The EC 7th Euratom Full Scale Demonstration of Plugs and Seals (DOPAS) framework project aims to improve the adequacy and consistency regarding industrial feasibility of plugs and seals, the measurement of their characteristics, the control of their behaviour over time in repository conditions and also their hydraulic performance acceptable with respect to the safety objectives. More information about the project, and associated publications, is available from the project website. • (2011-2013) The EC 7th Euratom Slow Processes in Close-to-equilibrium Conditions for Radionuclides in Water/Solid Systems of Relevance to Nuclear Waste Management (SKIN) framework project aimed to assess the effect of surface properties on apparent solubility as well as the kinetics of incorporation of radionuclides in the structure of a solid phase, and the associated reaction mechanisms for various solids in a systematic manner, using isotope exchange under close-to-equilibrium conditions. • (2010-2014) The EC 7th Euratom Long-term performance of Engineered Barrier Systems (PEBS) framework project aims to evaluate the sealing and barrier performance of a clay-based EBS with time, through development of a comprehensive approach involving experiments, model development and consideration of the potential impacts on long-term safety functions. • (2006-2009) The EC 6th Euratom Performance Assessment Methodologies in Application to Guide the Development of the Safety Case (PAMINA) framework project had a number of deliverables which relate to transport in the near field (the effect of hydrological change in an EBS on uranium transport, gas production and transport, and sensitivity analysis of distribution coefficients (Kd) and solubility limit models radionuclide migration in the near field). These reports, and further information about the PAMINA project on the web page. • (2005-2008) The EC 6th Euratom Fundamental Processes of Radionuclide Migration (FUNMIG) framework project aimed to develop a fundamental understanding of radionuclide migration processes in the geosphere, the application to performance assessment and communication of the results. The final scientific and technical report of the project is available on its web page.
IAEA	• N/A

4.3.e. What geologies have been and are being studied? Are there specific issues relating to these geologies which have required special consideration?

NEA	• (2010) The NEA Safety Case for Deep Geological Disposal of Radioactive Waste (AMIGO) project produced a report on *Geoscientific Information in the Radioactive Waste Management Safety Case: Main Messages from the AMIGO project*.
EC	• (2011-2014) The EC 7th Euratom Large Underground Concept Experiments (LUCOEX) framework project is considering a four repository concepts: horizontal disposal in Opalinus Clay, horizontal disposal in Callovo-Oxfordian clay, horizontal disposal in crystalline hard rock, and vertical disposal in crystalline hard rock. More information, and project reports, can be found at the project website. • (2005-2008) The EC 6th Euratom Fundamental Processes of Radionuclide Migration (FUNMIG) framework project aimed to develop a fundamental understanding of radionuclide migration processes in the geosphere for the three host rock types crystalline, clay and salt, the application to performance assessment and communication of the results. The final scientific and technical report of the project is available from the Cordis website: ftp://ftp.cordis.europa.eu/pub/fp6-euratom/docs/funmig_en.pdf. • (2003-2004) The EC 5th Euratom Network to Review Natural Analogue Studies and their Applications to Repository Safety Assessment and Public Communication (NANET) framework project sought to promote a more considered use of natural analogues in safety assessment and public communication. This was achieved by a critical review of traditional analogue studies, such as investigations of radionuclide transport around uranium ore bodies and analogues of processes such as glass degradation. More information about the project is available from the Cordis website: http://cordis.europa.eu/projects/rcn/67692_en.html.
IAEA	• (2004-ongoing) The IAEA URF network has several partners who are providing access to their URFs which are located in a variety of geologies. These include: clay (Belgium, France and Switzerland), granitic rocks (Canada, Japan, Korea, Sweden and Switzerland), igneous rocks (Czech Republic), mudstones (France), sedimentary rock (Japan), and salt (United States). More information about the network is available at https://nucleus.iaea.org/sites/connect/URFpublic/Pages/default.aspx. • (2003) Numerous far-field components and processes (transport in groundwater solute pathways, hydrogeology and water movement, water chemistry and chemical retardation, transport by groundwater, flow in partially saturated rocks, and the long-term stability of the disposal system) were discussed in the IAEA technical report on the *Scientific and Technical Basis for the Geological Disposal of Radioactive Wastes* (TRS-413). The report is available from the IAEA website: www-pub.iaea.org/MTCD/Publications/PDF/TRS413_web.pdf.

Clay geologies

NEA	• (1990-ongoing) The NEA established an international working group on argillaceous media in 1990, informally known as the Clay Club. The role of the Clay Club is to examine those argillaceous rocks that are being considered for the deep disposal of radioactive waste, which range from soft clays to indurated shales. Studies include clay media characterisation (mineralogy, geochemistry, porosity, pore geometry, hydraulic properties, etc.) and complementary numerical modelling. More information about the Clay Club, the member countries, recent activities and its publications, can be accessed via the NEA website: www.oecd-nea.org/rwm/clayclub.
EC	• (2010-2014) The 7th framework EC funded Processes Determining Cation Migration in Clay Rocks (CatClay) project aims to improve understanding of the phenomena governing migration of radionuclides in clay rocks as potential host rocks for the deep geological disposal of nuclear waste. The project focuses on the diffusion-driven transport of cationic species, Sr2+, Zn2+ and Eu3+, which are more or less strongly sorbed on clay mineral surfaces; it combines model and experimental developments. More information about the project can be found at the project website: http://cordis.europa.eu/result/rcn/159349_en.html. • (2001-2004) The EC 5th Euratom Fractures and Self-healing within the Excavation Disturbed Zone in Clays (SELFRAC) framework project aimed to better understand how the perturbation of the excavation for a geological disposal facility might induce a significant increase of the permeability, related to diffuse and/or localised crack proliferation in the clay host rock. More information about the project, and associated reports, are available from the Cordis website: http://cordis.europa.eu/projects/rcn/59929_en.html.
IAEA	• N/A

Salt geologies

NEA	• (2011-ongoing) The NEA established an international working group on geological rock salt formations in 2011. More information about the Salt Club, including the member countries, can be accessed via the NEA website: www.oecd-nea.org/rwm/saltclub.
EC	• (2000-2003) The EC 5th Euratom Backfill and Material Behaviour in Underground Salt Repositories, Phase II (BAMBUS II) framework project aimed to investigate interactions between backfill material and a salt host rock, utilising data from the Asse salt mine. More information about the project, and associated reports, are available from the Cordis website: http://cordis.europa.eu/projects/rcn/58654_en.html.
IAEA	• N/A

Crystalline geologies

NEA	• Most NEA work activities, unless explicitly specify, are applicable to crystalline rock formations. E.g. the NEA FEP database, AMIGO, MeSA.
EC	• (2011-2013) The 7th framework EC funded Crystalline Rock Retention Processes (CROCK) project has the overall objective to develop a methodology to reduce uncertainties in the long-term prediction of radionuclide migration in the crystalline rock far-field. More information about the project can be found at the project website: www.crockproject.eu.
IAEA	• N/A

4.3.f. What transport processes in the geosphere have been investigated?

NEA	• (1996-2001) The NEA Radionuclide Migration in Geologic, Heterogeneous Media (GEOTRAP) project aimed to promote exchange of information and in-depth discussions on approaches to acquiring field data and testing and modelling flow and transport of radionuclides in geologic formations for the purpose of site evaluation and safety assessment of deep repository systems. Five workshops were held as part of the project, covering a range of topics*. More information about this project, and its publications, can be found at the NEA website: www.oecd-nea.org/rwm/geotrap.html. • IGSC has issued a position paper on gas migration in early 2015 – www.oecd-nea.org/rwm/docs/2015/rwm-igsc2015-1-rev1.pdf.
EC	• (2009-2013) The 7th framework EC funded Fate of Repository Gases (FORGE) project aims to better understand gas generation and migration in multi-barrier (both natural and engineered) disposal system. Consideration has been given to EBS properties, excavation disturbed zone behaviour, far-field interactions, gas generation and up-scaling. More information about this project can be found at the project website: www.bgs.ac.uk/forge. • (2006-2009) The EC 6th Euratom Performance Assessment Methodologies in Application to Guide the Development of the Safety Case (PAMINA) framework project had a deliverable relating to gas production and transport in a Boom clay host rock. The report, and further information about the PAMINA project is available from the project website: www.ip-pamina.eu. • (2005-2008) The EC 6th Euratom Fundamental Processes of Radionuclide Migration (FUNMIG) framework project aimed to develop a fundamental understanding of radionuclide migration processes in the geosphere, the application to performance assessment and communication of the results. Diffusion was studied for the Clay far-field, advection and matrix diffusion for crystalline far-field and advection for the aquifer far-field around a salt host rock formation. The final scientific and technical report of the project is available from the Cordis website: ftp://ftp.cordis.europa.eu/pub/fp6-euratom/docs/funmig_en.pdf. • (2001-2004) The EC 5th Euratom Treatment of Geosphere Retention Phenomena in Safety Assessments (RETROCK) framework project aimed to develop a common basis for incorporating geosphere retention phenomena in safety assessments for deep geological repositories. More information on the project, and associated reports, is available from the Cordis website: http://cordis.europa.eu/projects/rcn/58527_en.html. • (2000-2003) The EC 5th Euratom Elaboration of hydromechanical Coupled Models by Interpretation of the Disturbances Observed during the Sinking of the Main Shaft of an Underground Laboratory in Eastern France (MODEX-REP) framework project aimed to both measure and model the response of the clay formation to drilling. The final report of the project is available from the Cordis website: http://cordis.europa.eu/documents/documentlibrary/92334551EN6.pdf. • (2000-2003) The EC 5th Euratom Migration Case Study: Transport of Radionuclides in a Reducing Clay Sediment (TRANCOM-II) framework project investigated the migration behaviour of radionuclides (U, Pu, Se and Am), identified as critical by performance assessment, in a reducing clay environment, with special emphasis on the role of the organic matter. More information about the project, and associated publications, is available from the Cordis website: http://cordis.europa.eu/projects/rcn/52867_en.html. • (2000-2002) The EC 5th Euratom Building Confidence in Deep Disposal: The Borehole Injection Sites at Tomsk-7 and Krasnoyarsk-26 (BORIS) framework project collected and evaluated data related to radionuclide migration at sites in Russia where liquid radioactive waste had been injected into the geological environment. More information about the project, and associated publications, are available at www.galson-sciences.co.uk/boris/default.htm.
IAEA	• N/A

* Field tracer transport experiments; modelling the effects of spatial variability; characterisation of water-conducting features and their representation in models; confidence in models of radionuclide transport; and geological evidence and theoretical bases for radionuclide-retention processes.

4.3.g. What research is being undertaken with respect to biosphere representation, transport within the biosphere and biosphere evolution for safety cases?

NEA	• (2001) The NEA IGSC discussed "The Role of the Biosphere in a Safety Case" in a topical session at the third IGSC meeting in 2001 (NEA/RWM/IGSC(2002)2). The report, published in 2002, is available from the NEA website: www.oecd-nea.org/rwm/docs/2002/rwm-igsc2002-2.pdf.
EC	• (2006-2008) The EC 6th Euratom Protection of the Environment from Ionising Radiation in a Regulatory Context (PROTECT) framework project aimed to develop dose rate thresholds for wildlife to help to determine the risk of exposure to ionising radiation. More details about the project, and associated publications, can be found at the project website: https://wiki.ceh.ac.uk/display/rpemain/protect. • (2004-2007) The EC 6th Euratom Environmental Risk from Ionising Contaminants: Assessment and Management (ERICA) framework project aimed to provide an integrated approach to scientific, managerial and societal issues concerned with the environmental effects of contaminants emitting ionising radiation, with emphasis on biota and ecosystems. The project was partly built on the achievements of the FASSET project, which provided a basic framework for the assessment of environmental impact of radionuclides. The final outcome of the project was the development of a user-friendly assessment tool with risk characterisation methodologies coupled with communication strategies aimed at decision making. More details about the project and the tool can be found at the project website: https://wiki.ceh.ac.uk/display/rpemain/erica. • (2000-2003) The EC 5th Euratom Environmental Protection from Ionising Contaminants in the Arctic (EPIC) framework project aimed to develop a framework for the protection of a pristine environment (Arctic) from radioactivity. Note that many of the outputs of this project were superseded by those of the ERICA project. More information on the project, and associated publications, can be found at the project website: https://wiki.ceh.ac.uk/display/rpemain/epic. • (2000-2003) The EC 5th Euratom BIOMOSA framework project investigated the development of site-specific biosphere models for performance assessment of nuclear waste disposals. The project also resulted with key conclusions which can be applied to the development of site-specific assessment tools. Key project results are documented in the BIOMOSA Project Report. • (2000-2003) The EC 5th Euratom Framework for Assessment of Environmental Impact (FASSET) framework project began the development of a framework for the assessment of environmental impact in radiation protection. More information about the project, and associated publications, can be found at https://wiki.ceh.ac.uk/display/rpemain/fasset. • (2000-2003) The EC 5th Euratom Modelling Sequential Biosphere Systems under Climate Change for Radioactive Waste Disposal (BIOCLIM) framework project aimed at providing a scientific basis and practical methodology for assessing the possible long-term impacts on the safety of radioactive waste repositories in deep formations due to climate and environmental change. More details on the project, and its publications, can be found at the project website: www.andra.fr/bioclim.
IAEA	• (2012-2015) The IAEA Modelling and Data for Radiological Impact Assessments (MODARIA) programme was set up to continue the IAEA's activities in the field of testing, comparing and developing guidance on the application of models to assess exposures to humans and radiological impacts on the environment. MODARIA has four themes, with between 1-4 working groups in each theme: remediation of contaminated areas, uncertainties and variability, exposures and effects on biota, and marine modelling. More information about MODARIA and the working groups can be found at the IAEA website: www-ns.iaea.org/projects/modaria. • (2009-2011) The IAEA EMRAS II programme was a follow-on of the EMRAS programme. There were three broad themes, with three working groups under each theme: reference approaches for human dose assessment, reference approaches for biota dose assessment and approaches for assessing emergency situations. More information about the EMRAS II programme, its working groups and associated publications, can be found at the IAEA website: www-ns.iaea.org/projects/emras/emras2. • (2003-2007) The IAEA Environmental Modelling for Radiation Safety (EMRAS) programme had the same aims as previous IAEA projects. The work of EMRAS focused on areas where uncertainties remain in the predictive capability of models, notably in relation to the consequences of releases of radionuclides to particular types of environment (e.g. urban and aquatic environments) restoration of sites with radioactive residues and impact of environmental radioactivity on non-human species. More information about the programme, and associated publications, can be found at the IAEA website: www-ns.iaea.org/projects/emras/emras-background.asp?s=8. • (1996-2001) The IAEA Biosphere Modelling and Assessment (BIOMASS) programme was concerned with developing and improving capabilities to predict the transfer of radionuclides in the environment. The programme had three themes: radioactive waste disposal, environmental releases and biosphere processes. The BIOMASS reports is available from the IAEA website: www-ns.iaea.org/projects/emras/emras-publications.asp?s=8. • (1986-1996) The IAEA Validation of Model Predictions (VAMP) programme was established following the Chernobyl disaster, and was established as a programme aimed at collating data from different IAEA member countries and co-ordinating model testing studies. It was concerned with models and data relevant to the terrestrial, aquatic and urban environments. It did not deal with models for atmospheric transport, but, however, considered the interactions of aerosols in the surface air with terrestrial and aquatic surfaces. The VAMP reports is available from the IAEA website: www-ns.iaea.org/projects/emras/emras-publications.asp?s=8.

4.3.h. What laboratories are there which can provide supporting evidence for aspects of the scientific basis of the safety case?

NEA	• N/A
EC	• The EC Institute for Transuranium Elements (JRC-ITU) conducts actinide research to study technological and medical applications of radionuclides/actinides: https://ec.europa.eu/jrc/en/about/itu.
IAEA	• (2011-ongoing) In 2011 the IAEA established an "International Network of Laboratories for Nuclear Waste Characterisation" (LABONET) to increase efficiency in sharing international experience in the application of proven, quality-assured practices for the characterisation of low- and intermediate-level radioactive waste and waste packages and to accelerate risk reduction and clean-up of the environmental legacy. More information on this network can be found on the IAEA website: www.iaea.org. • The IAEA has a number of environmental laboratories: radiometrics, radioecology, marine environmental studies and the terrestrial environment. Data collected in these laboratories can be used to inform the parameterisation of transfers in models used to support the safety case, and also potentially to support conceptual models also. More information about the IAEA environment laboratories is available from the IAEA website: www.iaea.org/nael/page.php.

4.4. Integration and management

4.4.a. How are safety cases documented?

NEA	• (2013) The NEA updated its 2004 brochure, based on experience gained since then by national organisations and international projects, "The Nature and Purpose of the Post-closure Safety Cases for Geological Repositories" (NEA Report No. NEA/RWM/R(2013)1). They took into account work that had been undertaken by the NEA during that time (including the MeSA project), the EC funded PAMINA project, new standards produced by the IAEA, and a number of safety reports that had recently been submitted by national waste management organisations and by their national or international peer reviews. The report is available from the NEA website: www.oecd-nea.org/rwm/reports/2013/78121-rwn-sc-brochure.pdf. • (2012) The NEA Methods for Safety Assessment of Geological Disposal Facilities for Radioactive Waste (MeSA) project published its final report in 2012 (NEA Report No. 6923). The report is available from the NEA website: www.oecd-nea.org/rwm/reports/2012/nea6923-mesa-initiative.pdf. • (2006-2009) The NEA set up a project "International Experiences in Safety Cases for Geological Repositories" (INTESC), which aimed to gather together safety case development experience within the IGSC. The project comprised a detailed questionnaire that was sent to IGSC members, which was later followed up with a workshop. The project report, published in 2009, is available from the NEA website: www.oecd-nea.org/rwm/reports/2009/nea6251-INTESC-eng.pdf. • (2004) The NEA IGSC published a brochure entitled *Post-closure Safety Case for Geological Repositories: Nature and Purpose* (NEA Report No. 3679). It was intended to stimulate the preparation of comprehensive evidentiary arguments for repository system long-term safety, typically extending to hundreds of thousands of years. The report is available at www.oecd-nea.org/rwm/reports/2004/nea3679-closure.pdf. In 2012, the IGSC revised the safety case brochure, incorporating the latest information of compiling a safety case: www.oecd-nea.org/rwm/reports/2013/78121-rwn-sc-brochure.pdf.
EC	• (2006-2009) The EC 6th Euratom Performance Assessment Methodologies in Application to Guide the Development of the Safety Case (PAMINA) framework project published a handbook on the state-of-the-art safety assessments of geological repositories. More information on the PAMINA project, the handbook and other associated publications, can be found at the project website: www.ip-pamina.eu.
IAEA	• (2012) The IAEA produced as part of its safety standard series a report titled *The Safety Case and Safety Assessment for the Disposal of Radioactive Waste* (SSG-23), www-pub.iaea.org/mtcd/publications/pdf/pub1553_web.pdf. • (2011) Following the publication of SSR-5, the IAEA published a Specific Safety Guide (No. SSG-14) relating specifically to *Geological Disposal Facilities for Radioactive Waste*. As with SSR-5, this also superseded previous safety guides.* The report is available from the IAEA website: www-pub.iaea.org/MTCD/publications/PDF/Pub1483_web.pdf. • (2011) The IAEA produced as part of its safety standard series a report titled *Disposal of Radioactive Waste* (Specific Safety Requirements No. SSR-5). This report superseded a number of previous safety series reports, which had previously focused on specific aspects of waste disposal.** The report is available from the IAEA website: www-pub.iaea.org/MTCD/publications/PDF/Pub1449_web.pdf. • (2009) The IAEA produced as part of its General Safety Requirements series a report titled *Safety Assessment for Facilities and Activities* (GSR-4). This includes a section on the management, use and maintenance of the safety assessment, www-pub.iaea.org/MTCD/publications/PDF/Pub1375_web.pdf. • (2008) The IAEA produced as part of its safety standards series the Safety Guide (GS-G-3.4) *The Management System for the Disposal of Radioactive Waste*, www-pub.iaea.org/MTCD/publications/PDF/Pub1330_web.pdf.

* *Safety Assessment for Near Surface Disposal of Radioactive Waste* (WS-G-1.1, 1999). ** *Near Surface Waste Disposal* (WS-R-1, 1999), *Geological Disposal of Waste* (WS-R-4, 2006), *Radioactive Waste Disposal into the Ground* (1965), *Safety Principles and Technical Criteria for the Underground Disposal of High Level Radioactive Wastes* (1989).

4.4.b. What is optimisation and how is it demonstrated?

NEA	• (2010) The NEA produced a report on *Optimisation of Geological Disposal of Radioactive Waste* (NEA Report No. 6836), considering national and international guidance and questions for further discussion. The report is available from the NEA website: www.oecd-nea.org/rwm/reports/2010/nea6836-optimisation-ENG.pdf.
EC	• N/A
IAEA	• (2006) In the IAEA *Fundamental Safety Principles* (SF-1), principle 5 relates to the optimisation of protection. The report is available from the IAEA website: www-pub.iaea.org/MTCD/publications/PDF/Pub1273_web.pdf.

4.4.c. How are uncertainties (future, models and data) dealt with or recommended to be handled?

NEA	• (2004) The NEA FSC produced a secretariat paper on "The mental models approach to risk research: A radioactive waste management perspective". This is available from the NEA website: www.oecd-nea.org/rwm/docs/2004/rwm-fsc2004-7-rev1.pdf. • (2008) The IGSC also examined uncertainties management in its MeSA project. Key results are documented in the "Project Synthesis Report".
EC	• (2006-2009) The EC 6th Euratom Performance Assessment Methodologies in Application to Guide the Development of the Safety Case (PAMINA) framework project included a research and technological development component relating specifically to the treatment of uncertainty during safety case development. The reports of that working group, and other information and publications produced during the PAMINA project, can be found at the project website: www.ip-pamina.eu.
IAEA	• (In preparation) The IAEA is currently compiling a safety guide relating to "Risk-Informed Decision Making". More information on this safety guide, together with information about the other IAEA reports it will interface with, can be found at the IAEA website: www-ns.iaea.org/downloads/standards/dpp/dpp365.pdf.

4.4.d. How is the iterative nature of safety cases managed?

NEA	• (2013) The NEA report on "The Nature and Purpose of the Post-Closure Safety Cases for Geological Repositories" discusses the iterative nature of the safety case, and how doing so provides a framework for the safety case to be revised and updated as scientific and technical data underpinning it evolves as the development progresses, regulatory requirements evolve, and wider socio-political consultation occurs. The report is available from the NEA website: www.oecd-nea.org/rwm/reports/2013/78121-rwn-sc-brochure.pdf.
EC	• N/A
IAEA	• (2011) The IAEA has produced a report on *The Management System for the Development of Disposal Facilities for Radioactive Waste* (NW-T-1.2), recognising the iterative nature of the safety case. The report is available from the IAEA website: www-pub.iaea.org/MTCD/Publications/PDF/P1496_web.pdf.

4.4.e. What quality and knowledge management systems are in place for safety cases?

NEA	• (2014-ongoing) The NEA IGSC has recently instigated a Radioactive Waste Repository Metadata Management (RepMet) project. This is focused on a shorter term than that of the RK&M initiative. • (2010-ongoing) The NEA RK&M initiative is focused on the long-term preservation of records, knowledge and memory. More information about the RK&M initiative is available from the NEA website: www.oecd-nea.org/rwm/rkm.
EC	• N/A
IAEA	• (2011) The IAEA produced a report on *The Management System for the Development of Disposal Facilities for Radioactive Waste* (NW-T-1.2). Section 3.8 notes that information and knowledge preservation and transfer are activities that require careful definition for a geological repository, but that there is not yet practical experience of any such activities being implemented. The report is available at www-pub.iaea.org/MTCD/Publications/PDF/P1496_web.pdf. • (2011) The IAEA produced a report on *Comparative Analysis of Methods and Tools for Nuclear Knowledge Preservation* (NG-T-6.7), www-pub.iaea.org/MTCD/Publications/PDF/Pub1494_web.pdf. • (2008) The IAEA produced, as part of its safety standards series the Safety Guide (GS-G-3.4), *The Management System for the Disposal of Radioactive Waste*. The report is available from the IAEA website: www-pub.iaea.org/MTCD/publications/PDF/Pub1330_web.pdf.

4.4.f. What training programmes are there to ensure both capacity and knowledge are retained over the timescales relevant to a repository life cycle?

NEA	• N/A
EC	• (2013-2017) The EC 7th Euratom Coordination and Implementation of a pan-European Instrument for Radioecology (COMET) framework project aims to strengthen the pan-European research initiative on the impact of radiation on man and the environment by facilitating the integration of radioecological research. More information about the project is available from the project website: https://wiki.ceh.ac.uk/display/COM/comet+Home. • (2012-2013) The EC 7th Euratom Sustainable Network of Independent Technical Expertise for Radioactive Waste Disposal (SITEX) framework project aimed to identify the efficient means that should be developed through the establishment of a sustainable expertise function network within a European framework. More information can be found about this project on the Cordis website: http://cordis.europa.eu/projects/rcn/101495_en.html. • (2011-2015) The EC 7th Euratom Strategy for Allied Radioecology (STAR) framework project aims to establish a network of excellence in radioecology. The goal is to efficiently integrate important organisations, infrastructures, and research efforts into a sustainable network that contributes to a European research area in radioecology. More information about the project, and associated publications, are available at https://wiki.ceh.ac.uk/display/star/the+radioecology+exchange. • (2009-ongoing) The EC 7th Euratom Programme for Education, Training and Research on Underground Storage (PETRUS II and III*) framework projects aim to build on the work undertaken by the European Nuclear Engineering Network (ENEN) Association, developing** and implementing*** a PETRUS training programme. The objective is to set up accredited and recognised qualification in geological disposal that can be achieved in parallel both through formal and professional development training programmes. More information about the projects is available in a presentation given at the Euradwaste '13 Conference, which is available from the Cordis website: http://cordis.europa.eu/fp7/euratom-fission/docs/euradwaste13-bazargan-sabet.pdf. Knowledge, skill transfers, as well as competence maintenance through education and training are also addressed in IGD-TP CMET JA14 at www.igdtp.eu/index.php/joint-activities/competence-maintenance-education-and-training-cmet. • (2007-2009) The EC 6th Euratom Future for Radioecology in Europe (FUTURAE) framework project undertook a feasibility study into the establishment of a network of excellence of radioecology as part of framework 7. This lead to the founding of the STAR network in 2011. More information about the project is available from the French Institute for Radiological Protection and Nuclear Safety (IRSN) website: www.irsn.fr/en/research/research-organisation/research-programmes/futurae/pages/the-european-futurae-project-3275.aspx. • (2002-2003, 2006-2009) The EC 5th Euratom ENEN framework project aimed to produce a handbook, proposing a global network strategy, defining the major elements for a European network for nuclear engineering education and to perform pilot sessions on European nuclear education. This was later followed up by the ENEN-II project, funded under the EC 6th Euratom framework, which aimed at developing and ENEN Association in a sustainable way in the areas of nuclear engineering, radioprotection and radioactive waste management, including underground disposal. More information about ENEN is available from the network website: www.enen-assoc.org.
IAEA	• (Ongoing) The IAEA offers a range of specialised training courses, developed by the Division of Radiation, Transport and Waste Safety. Examples of safety case relevant courses include: safe transport of radioactive material; reference training material on safety assessment of near-surface low- and intermediate-level radioactive waste disposal facilities; and, regional training material on waste management. A more extensive list of training courses, and contact details, are available from the IAEA website: www-ns.iaea.org/training/rw/special-train-courses.asp. • (2009-ongoing) The IAEA International Low Level Radioactive Waste Disposal Network (DISPONET) network aims to co-ordinate support to organisations or member states with less advanced programmes for disposal of low-level waste, by making available the relevant skills, knowledge, managerial approaches and expertise from member states with operating disposal facilities. This is done via training courses, workshops and conferences. The scope of this network includes: low-level waste, Intermediate-level waste and very-low-level waste, including disused sealed radioactive sources; facilities for surface and subsurface disposal, including borehole disposal; and the whole lifecycle of the disposal facility+. More information on DISPONET is available at www.iaea.org/ourwork/st/ne/nefw/wts-networks/disponet/overview.html. • (2001-ongoing) Since 2001, the IAEA has championed the concept and use of professional networks to advance best practices in nuclear knowledge management, implementation of nuclear technology, radioactive waste management, decommissioning and environmental remediation. This is done through its Connecting the Network of Networks for Enhanced Communication and Training (CONNECT) programme. There are, in 2014, seven networks# sponsored by the IAEA under this programme, with additional funding from the EC. More information about CONNECT and the underlying networks is available at http://nucleus.iaea.org/sites/connect/Pages/default.aspx.

* PETRUS I was ENEN-II (http://cordis.europa.eu/fp7/euratom-fission/docs/euradwaste13-bazargan-sabet.pdf). ** PETRUS II. *** PETRUS III.

\+ Planning, siting, design, construction, assessment of safety, operation, closure, monitoring and institutional control; Different stages of repository development.

\# The Underground Research Facilities for Geological Disposal (URF), the Networking Nuclear Education (NNE), the International Low Level Radioactive Waste Disposal Network (DISPONET), the International Decommissioning Network (IDN), the Management System Network (MSN), the Coordination Group for Uranium Legacy Sites (CGULS), the Nuclear Knowledge Management (NKM) and the Environmental Remediation and NORM Management Network (ENVIRONET).

4.4.g. What measures are recommended to build confidence in the safety case?

NEA	• (1999) The NEA produced a report on *Confidence in the Long-term Safety of Deep Geological Repositories: Its Development and Communication*. This report is available from the NEA website: www.oecd-nea.org/rwm/reports/1999/confidence.pdf.
EC	• Council Directive 2011/70/Euratom recommends the use of peer review as a means to build confidence. • EC E-TRACK, by promoting public participation, enhances confidence. • Eurobarometer, since 1973, has been monitoring public opinions to keep abreast of the societal views: http://ec.europa.eu/public_opinion/description_en.htm.
IAEA	• (2005) At the 5th IAEA WATEC Meeting*, a topical session was held on building confidence in geological disposal. The presentations from that meeting are available at: www.iaea.org/OurWork/ST/NE/NEFW/wts_watec_meetings_2005.html.

* International Radioactive Waste Technical Committee (WATEC), which is a committee under the Waste Technology Section (WTS) of the IAEA.

Additional work relating to building confidence in the safety case relating to stakeholders, and stakeholder engagement, is considered in the below Question h.

4.4.h. What are the current recommendations with respect to stakeholder involvement?

NEA	• (2012) The NEA FSC undertook a study into "Clarity, Conflict and Pragmatism: Challenges in Defining a 'Willing Host Community'". The associated report is available at: www.oecd-nea.org/rwm/docs/2012/rwm-r2012-4.pdf. • (2012) The NEA FSC undertook a study into "Reflections on Siting Approaches for Radioactive Waste Facilities: Synthesizing Principles Based on International Learning". The associated report is available from the NEA website: www.oecd-nea.org/rwm/docs/2012/rwm-r2012-5.pdf. • (2010) The NEA FSC undertook a study into *More than Just Concrete Realities: The Symbolic Dimension of Radioactive Waste Management*. The associated report is available from the NEA website: www.oecd-nea.org/rwm/reports/2010/nea6869-symbolic.pdf. • (2010) The NEA FSC published a report as how partnership approaches between waste management organisations and the host communities of any proposed disposal site evolved and been implemented by NEA member states, *Partnering for Long-term Management of Radioactive Waste: Evolution and Current Practice in Thirteen Countries* (NEA No. 6823). The report was based on work undertaken by the UK NDA RWMD* in 2007. This report is available from the NEA website: www.oecd-nea.org/rwm/pubs/2010/6823-partnering-management.pdf. • (2008) The NEA FSC held a topical session on the use of analogues to help understand and build confidence in radioactive waste management approaches and safety cases. The proceedings of this topical session, "Link between Research, Development and Demonstration (RD&D) and Stakeholder Confidence: Use of Analogues for Confidence Building", is available at: www.oecd-nea.org/rwm/nea_rwm_fsc_2008_3_analogues_olis.pdf. • (2007-2008) The NEA FSC held a topical session on the link between RD&D and stakeholder confidence with respect to long-term safety in June 2007. The proceedings of this topical session, "Link between Research, Development and Demonstration (RD&D) and Stakeholder Confidence: the Specific Aspect of Long-term Safety", is available from the NEA website: www.oecd-nea.org/rwm/docs/2008/rwm-fsc2008-2.pdf. • (2007) The NEA FSC undertook a study into *Cultural and Structural Changes in Radioactive Waste Management Organisations – Lessons Learnt*. The associated report is available from the NEA website: www.oecd-nea.org/rwm/reports/2007/nea6180-cultural.pdf. • (2007) The NEA FSC undertook a study into *Fostering a Durable Relationship Between a Waste Management Facility and its Host Community: Adding Value through Design and Process*. The associated report is available from the NEA website: www.oecd-nea.org/rwm/reports/2007/nea6176-fostering.pdf. • (2007) At the 6th meeting of the NEA Working Party on the Management of Materials from Decommissioning and Dismantling (WPDD), a topical session on stakeholder involvement in decommissioning projects was held. Although the area of concern was not geological disposal, the national practices and experiences discussed at that meeting should nonetheless be of interest to the IGSC. A report on stakeholder engagement was prepared after the meeting, and is available from the NEA website: www.oecd-nea.org/rwm/reports/2007/nea6320-stakeholder.pdf. • (2004) The NEA FSC produced a short guide and annotated bibliography of "Stakeholder Involvement Techniques". The guide is available from the NEA website: www.oecd-nea.org/rwm/docs/2004/rwm-fsc2004-7.pdf. • (2004) The NEA FSC produced a report based on the work undertaken during its first four years of activity (2000-2004) *Learning and Adapting to Societal Requirements for Radioactive Waste Management: Key Findings and Experience of the Forum on Stakeholder Confidence*. The report is available from the NEA website: www.oecd-nea.org/rwm/reports/2004/nea5296-societal.pdf. • (2003) The NEA FSC undertook a study into *Public Information, Consultation and Involvement in Radioactive Waste Management*. The associated report is available at: www.oecd-nea.org/rwm/reports/2003/nea4430-publicinfo.pdf.

* Nuclear Decommissioning Agency, Radioactive Waste Management Directorate.

EC	• (2011-2013) Directive 2011/70/Euratom states the importance of stakeholder involvement and transparency. The EC 7th Euratom Implementing Public Participation Approaches in Radioactive Waste Disposal (IPPA) framework project has the primary aim to establish arenas where different stakeholders can move forward together to increase their understanding of the issues involved in radioactive waste disposal and of their respective views. The focus is on implementation in some central and eastern European countries. They have also developed and implemented an online tool to guide the selection of the means of stakeholder engagement for a given circumstance*. More information about the project, and associated publications, can be found on the project website: www.ippaproject.eu. • (2006-2009) The EC 6th Euratom Performance Assessment Methodologies in Application to Guide the Development of the Safety Case (PAMINA) framework project held a stakeholder engagement workshop in 2008, "Communicating Safety Issues for a Geological Repository". The workshop report is available from the project website: www.ip-pamina.eu/downloads/pamina2.1.b.1.pdf. • (2003-2004) The EC 5th Euratom Network to Review Natural Analogue Studies and their Applications to Repository Safety Assessment and Public Communication (NANET) framework project sought to promote a more considered use of natural analogues in safety assessment and public communication. This was achieved by a critical review of traditional analogue studies, such as investigations of radionuclide transport around uranium ore bodies and analogues of processes such as glass degradation. More information about the project is available from the Cordis website: http://cordis.europa.eu/projects/rcn/67692_en.html.
IAEA	• IAEA NG-T-1.4 – *Stakeholder involvement throughout the life cycle of nuclear facilities*, as well as Safety Standards GS-R-3 state the importance of taking stakeholders' expectations into consideration in planning/developing all nuclear facilities, www-pub.iaea.org/MTCD/publications/PDF/Pub1520_web.pdf; www-pub.iaea.org/MTCD/publications/PDF/Pub1252_web.pdf.

* The circumstances for the stakeholder engagement are based on a number of factors in the tool: level of decision making, phase of decision-making, number of stakeholders involved, combination of stakeholders, participation level, frequency of meetings, and who is implementing the engagement.

4.4.i. *What recommendations relate to the regulatory review process?*

NEA	• (2012) The NEA produced a report on *The Evolving Role and Image of the Regulator in Radioactive Waste Management: Trends over Two Decades* (NEA No. 7083). The report is available from the NEA website: www.oecd-nea.org/rwm/docs/2012/7083-evolving-role-and-image.pdf. • (2009) The NEA Regulators' Forum of the RWMC undertook a review of both national and international developments with respect to regulatory issues in the field of geological disposal, publishing a report titled *Regulation and Guidance for the Geological Disposal of Radioactive Waste: Review of Literature and Initiatives of the Past Decade* (NEA No. 6405). The report is available from the NEA website: www.oecd-nea.org/rwm/reports/2010/nea6405-regulation-guidance-ENG.pdf. • (2005) Although not related directly to regulatory review, the NEA undertook a survey of principles and good practice for safety cases with respect to "International Peer Reviews in the field of Radioactive Waste". The outcome of that survey is available from the NEA website: www.oecd-nea.org/rwm/docs/2005/rwm-peer2005-2.pdf. • (2003) The NEA FSC undertook a study into *The Regulator's Evolving Role and Image in Radioactive Waste Management*. The associated report is available from the NEA website: www.oecd-nea.org/rwm/reports/2003/nea4428-regulator-role.pdf. • (1997) The NEA held a workshop on "Regulating the Long-term Safety of Radioactive Waste Disposal". The proceedings are not publicly available.
EC	• (2012-2013) The EC 7th framework, the SITEX programme evaluated how to co-ordinate skills developed, by both waste management organisation and regulatory bodies, in proceeding with the decision-making process. Further information at http://sitexproject.eu. • (2011) Council Directive 2011/70/Euratom describes the responsibilities of different stakeholders and the key elements in the process. • (2007-2009) The EC 6th Euratom framework project CIP (New Governance approaches to radioactive waste management in Europe: Cowam in practice), in which stakeholders participated directly in both the research groups and the steering committee had four key aims. These were: to contribute to make actual progress in the governance of radioactive waste management (RWM); follow up and analyse five national processes of RWM governance (Spain, United Kingdom, Romania, Slovenia and France); support stakeholders, particularly local communities, directly in their engagement, and to capture the learning from that experience for the EU 27. More information on the project, and associated publications, can be found at the project website: www.cowam.com/?-Cowam-in-practice.

EC	• (2006-2008) The EC 6th Euratom European Observatory for Long-term Governance on Radioactive Waste Management (OBRA) framework project aimed to assess the feasibility of creating an observatory for long-term governance on radioactive waste management. OBRA explored whether such an observatory would be a useful mechanism for all stakeholders firstly, to access to the knowledge generated by successive EU research programmes, both in scientific and social sciences fields; secondly, to promote the most appropriate forms of interaction between them and thirdly, to jointly define how results from research, training and development in radioactive waste management and disposal are formulated and how their dissemination is managed. A final activity report is available from the following website, though it should be noted that the project website given within this report is no longer active: ftp://ftp.cordis.europa.eu/pub/fp6-euratom/docs/obra-publishable-final-activity-report_en.pdf. • (2004-2006) The EC 6th Euratom framework project COWAM-2 built a research partnership between stakeholders and research contractors on each of these four key issues, and supported continued networking efforts that had been initiated during COWAM. With this partnership, stakeholders have had the opportunity to frame and feed the production of knowledge so that it better addresses the questions they identified as the most relevant to improve the robustness of decision-making processes in radioactive waste management. More information on the project, and associated publications, can be found at the project website: www.cowam.com/?cowam-2-final-reports. • (2000-2003) The EC 5th framework project COWAM (Comparison of decision-making processed at the local and regional community level in nuclear waste facility siting) created a European network on radioactive waste governance. More information on the project, and associated publications, can be found at the project website: www.cowam.com/?-cowam1.
IAEA	• (In preparation) Working Group 3 (Reference Models for Waste Disposal) of the IAEA EMRAS II programme considered demonstration of compliance with protection objectives. They reviewed international fundamentals, requirements and guides, and discussed examples of national applications of the international guidance. The report is current awaiting publication*. (1997) The IAEA Working Group on Principles and Criteria for Radioactive Waste Disposal was set up in 1991, and reported on *Regulatory Decision Making in the Presence of Uncertainty in the Context of the Disposal of Long Lived Radioactive Wastes* (TECDOC-975). The report is available from the IAEA website: www-pub.iaea.org/MTCD/publications/PDF/te_975_prn.pdf.

* IAEA (2012). Environmental Modelling for RAdiation Safety (EMRAS II) Programme. Report of Working Group 3, "Environmental Change in Post-Closure Safety Assessment of Solid Radioactive Waste Repositories". Final Draft Report of WG3 submitted October 2012 by WG participants to IAEA for publication.

Chapter 5. Potential work areas for safety case enhancement

In addressing the questions set out in the preceding sections, it is clear that there exists a large volume of documentation/considerable number of projects which have been undertaken, with respect to a wide range of aspects relating to the safety case for the geological disposal of radioactive waste. Broadly speaking, the trend seems to suggest that the NEA Integration Group for the Safety Case (IGSC) has tended to consolidate knowledge and experiences gained internationally, where the IAEA has been dominant in producing guidance relating to wider aspects of the safety case, and the EC has tended to focus on guiding member states in establishing national safety policies and regulatory framework. EC funding is also provided to the necessary research and development activities to address specific aspects of developing a safety case. Noting that these organisations have also engaged in activities which indirectly support safety case development, e.g. the NEA thermodynamics database providing inputs to safety calculations, the various IAEA biosphere projects that addressed particular safety case related issues; the EC Performance Assessment Methodologies in Application to Guide the Development of the Safety Case (PAMINA) project which looked over the whole safety assessment methodology, etc., the work of the three agencies share a similar goal of enhancing safety of developing geological repositories for radioactive waste. While there is unavoidable overlap in setting the contexts and constraints of these research projects, these work activities often provide a complement to each other in enhancing the completeness of the topic being studied.

In reviewing recent work activities and developing this source book, the IGSC noted a number of gaps that exist in the documentation with respect to safety case development and key components of the safety case, which may be considered in future IGSC work.

5.1. Site characterisation, screening and selection

While much work has been undertaken in this area at the national level, by individual waste management programmes, there is little international guidance available due to the differences in the national programmes. A summary review of site characterisation, screening and selection approaches used in practice from national programmes, with best practices defined, could provide a useful source for other organisations whose waste disposal programmes are less advanced.

5.2. Data integration and quality assurance to support safety assessments

The system safety evaluation relies on either full-blown process models that are linked or abstracted models that are linked. It is important to assure that whatever data needs there are for these models, that these data be reviewed so that internal consistency is assured. These very large and multiple-sourced data sets can be housed and maintained in a controlled multidimensional data model from which subcomponent models and process models draw their data. This is a topic that integrates all of the supporting sciences with design and involves quality assurance. Data integrity underlies model credibility.

5.3. Containers for waste other than spent fuel

While the IAEA has an established working group for the *Dual Use Cask for Spent Fuel*, there do not appear to be any international projects or groups working on, or sharing information and experience on, the containers for any other waste categories (e.g. low-level waste, intermediate-level waste and high-level waste [HLW]) or potentially difficult waste forms (e.g. organic wastes). At the national level a range of containers have been considered for various waste forms (e.g. containers for low-level waste and intermediate-level waste for the proposed deep geological repository in Ontario, Canada – see OPG, 2010; a range of containers have been studied by the UK Nuclear Decommissioning Authority [NDA][1]). A document bringing together the experiences and studies undertaken at the national level may provide a useful source for those countries with less advanced radioactive waste disposal programmes. Such report will also provide beneficial information for long-term management and/or extended storage of radioactive waste which many national programmes are currently facing.

5.4. Optimisation in safety cases

The NEA Radioactive Waste Management Committee (RWMC) produced a report which considered national and international guidance with respect to the optimisation of geological disposal of radioactive waste in 2010 (NEA No. 6836). As a number of national geological disposal programmes, e.g. Swedish, Finnish and Canadian, are continuing their progress in terms of their disposal facility design and the construction phase, a review of optimisation in practice as well as the impact of optimisation on the repository design would be useful to enhance the design and the construction of the facilities.

5.5. Repository operational safety

Both the IGSC and the IAEA have initiated projects addressing operational safety issues. The February 2014 fire and radiation-release events at the Waste Isolation Pilot Plant in New Mexico, United States, are being thoroughly investigated and the causes for these events and the operational response to them has been critically documented and followed by corrective action suggestions from the accident investigation team. These mishaps at a facility that was very proud of its almost 15 years of safe operations is a good reminder for the world's repository programmes that success can breed some degree of complacency, and can lead to shortcuts when funding is tight. The ongoing work in this area at the NEA (e.g. the Expert Group on Operational Safety [EGOS]) and the IAEA International Inter-comparison and Harmonisation Project on Demonstrating the Safety of Geological Disposal (GEOSAF) projects should continue and to learn from these mishaps.

5.6. Shielding and criticality

Fissile material is involved in the operation of many fuel cycle facilities and in the management of radioactive waste. Many activities at these facilities may entail substantial changes of the radioactivity which may result in a release of radiation that can be lethal to nearby personnel. The Working Party on Nuclear Criticality Safety (WPNCS) of the NEA Nuclear Science Committee evaluates technical and scientific issues relevant to criticality safety in nuclear fuel cycle particularly in fuel fabrication, transport and storage.

1. The NDA bibliography, which is searchable, is available from the following website: www.nda.gov.uk/documents/biblio.

With respect to the management of spent fuel and radioactive waste containing fissile materials (i.e. handling, processing, storage, disposal), experience has shown that safe radioactive management can be performed when proper precautions are exercised. To ensure subcriticality both during normal operation and in accidents, some countries have developed their national guidance for nuclear criticality safety (e.g. Canada, United States). In developing specific criticality safety guidance, key principles and elements consistent with international standards are often followed. It seems the only international guidance in this area is the IAEA's Safety Standards on Criticality Safety in the Handling of Fissile Materials, SSG-27 which covers various aspects of criticality safety from the nuclear power plant through to disposal (i.e. handling, transport, storage, reprocessing of spent fuel, processing of radioactive waste and its disposal). Specifically the criteria for ensuring adequate required shielding and confinement of fissionable materials also seem to be non-existent.

Noting the fact that a generic guidance document may have limited usefulness as shielding requirements are country-, concept-, and waste-specific, an overview of how criticality safety is addressed in safety assessments may provide valuable information for the prevention of criticality accidents in the handling, storage, processing, and transportation of fissionable materials and the long-term management of nuclear waste.

References

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EC (2009), *Implementing Geological Disposal of Radioactive Waste Technology Platform – Special Report: Vision Document*, ISBN 973-92-79-13622-1, EC, Brussels.

Limer, L. (2014), "NEA Safety Case Sourcebook: Pre-disposal Storage", A Quintessa Limited Report for the NEA, QRS-1696A-TN2, version 0.3, February 2014.

NEA (2013a), "The Nature and Purpose of the Post-closure Safety Cases for Geological Repositories", NEA/RWM/R(2013)1.

NEA (2013b), "Working Party on Decommissioning and Dismantling (WDPP): Sourcebook of the IAEA, EC and NEA References in Decommissioning", NEA/RWM/WPDD(2013)1.

OPG (2010), "Reference Low and Intermediate Level Waste Inventory for the Deep Geologic Repository", OPG Report, 00216-REP-03902-00003-R03.

Thorne, M., L. Limer and G. Smith (2011), "NDA RWMD Biosphere Assessment Studies FY2010-2011: Review of Biosphere Characterisation Studies Undertaken by Selected Waste Management Organisations and Derived Guidance to RWMD Biosphere Assessment Studies", QRS-1378W-3, Version 1.0 (Final).

Appendix A. List of NEA documents on safety cases

Table A.1. General documentation

Year	Title	Publication ID
2014	"Local Communities' Expectations and Demands on Monitoring and the Preservation of Records, Knowledge and Memory of a Deep Geological Repository"	NEA/RWM/R(2013)4
2013	"Underground Research Laboratories"	NEA/RWM/R(2013)2
2013	"The Nature and Purpose of the Post-Closure Safety Cases for Geological Repositories"	NEA/RWM/R(2013)1
2012	"Indicators in the Safety Case – An NEA Status Report"	NEA/RWM/R(2012)7
2012	"Reflections on Siting Approaches for Radioactive Waste Facilities: Synthesizing Principles Based on International Learning"	NEA/RWM/R(2012)5
2012	"Clarity, Conflict and Pragmatism: Challenges in Defining a 'Willing Host Community'"	NEA/RWM/R(2012)4
2012	"Cementitious Materials in Safety Cases for Geological Repositories for Radioactive Waste: Role, Evolution and Interactions"	NEA/RWM/R(2012)3
2012	*Reversibility and Retrievability in Planning for Geological Disposal of Radioactive Waste: Considerations for National Geological Disposal Programmes*	NEA No. 7085
2012	*Short Brochure of Principal R&R Project Findings*	NEA No. 7085
2012	*The Evolving Role and Image of the Regulator in Radioactive Waste Management*	NEA No. 7083
2012	*Methods for Safety Assessment for Geological Disposal Facilities for Radioactive Waste*	NEA No. 6923
2012	*Thermodynamic Sorption Modelling in Support of Radioactive Waste Disposal Safety Cases*	NEA No. 6914
2011	"Final Report of the NEA Retrievability and Reversibility Project"	NEA/RWM/R(2011)4
2010	*Reversibility and Retrievability in Planning for Geological Disposal of Radioactive Waste: Proceedings of the "R&R" International Conference and Dialogue, 14-17 December 2010, Reims, France*	NEA No. 6993
2010	*More than Just Concrete Realities: The Symbolic Dimension of Radioactive Waste Management*	NEA No. 6869
2010	*Optimisation of Geological Disposal of Radioactive Waste*	NEA No. 6836
2010	*Partnering for Long-term Management of Radioactive Waste: Evolution and Current Practice in Thirteen Countries*	NEA No. 6823
2010	*AMIGO: Geoscientific Information in the Radioactive Waste Management Safety Case*	NEA No. 6395
2010	*Self-sealing of Fractures in Argillaceous Formations in the Context of Geological Disposal of Radioactive Waste*	NEA No. 6184
2010	"The Joint EC/NEA Engineered Barrier System Project: Synthesis Report"	EUR 24232 EN
2009	*AMIGO 3rd WS Proceedings: Approaches and Challenges for the Use of Geological Information in the Safety Case for Deep Disposal of Radioactive Waste*	NEA No. 6417

Table A.1. General documentation *(cont'd)*

Year	Title	Publication ID
2009	*Regulation and Guidance for the Geological Disposal of Radioactive Waste: Review of Literature and Initiatives of the Past Decade*	NEA No. 6405
2009	*Natural Tracer Profiles across Argillaceous Formations, The CLAYTRAC Project*	NEA No. 6253
2009	*INTESC: International Experience in Developing Safety Cases, Project Outcomes*	NEA No. 6251
2008	"Link Between Research, Development and Demonstration (RD&D) and Stakeholder Confidence: Use of Analogues for Confidence Building"	NEA/RWM/FSC(2008)3
2008	"Link between Research, Development and Demonstration (RD&D) and Stakeholder Confidence: the Specific Aspect of Long-term Safety"	NEA/RWM/FSC(2008)2
2007	*Stakeholder Involvement in Decommissioning Nuclear Facilities: International Lessons Learnt*	NEA No. 6320
2007	*Cultural and Structural Changes in Radioactive Waste Management Organisations – Lessons Learnt*	NEA No. 6180
2007	*Fostering a Durable Relationship Between a Waste Management Facility and its Host Community; Adding Value through Design and Process*	NEA No. 6176
2006	*EBS in the Safety Case: Design Confirmation and Demonstration*	NEA No. 6257
2005	*Interpretation and Prediction of Radionuclide Sorption onto Substrates Relevant for Radioactive Waste Disposal Using Thermodynamic Sorption Models*	NEA No. 5992
2005	"International Peer Reviews in the field of Radioactive Waste"	NEA/RWM/PEER(2005)2
2005	*Linkage of Geoscientific Arguments and the Line of Evidence Supporting the Safety Case*	NEA No. 6119
2005	*EBS in the Safety Case: The Role of Modelling*	NEA No. 6118
2005	*Stability and Buffering Capacity of the Geosphere for Long-term Isolation of Radioactive Waste*	NEA No. 5303
2005	*Clay Club Catalogue of Characteristics of Argillaceous Rocks*	NEA No. 4436
2004	"Stakeholder Involvement Techniques – A Short Guide and Annotated Bibliography"	NEA/RWM/FSC(2004)7
2004	"The mental models approach to risk research: A radioactive waste management perspective"	NEA/RWM/FSC(2003)7/REV1
2004	*EBS in the Context of the Entire Safety Case: Process Issues*	NEA No. 6001
2004	*Learning and Adapting to Societal Requirements for Radioactive Waste Management: Key Findings and Experience of the Forum on Stakeholder Confidence*	NEA No. 5296
2004	*Post-Closure Safety Case for Geological Repositories: Nature and Purpose*	NEA No. 3679
2003	*EBS in the Context of the Entire Safety Case: Design Requirements and Constraints*	NEA No. 4548
2003	*Features, Events and Processes Evaluation Catalogue for Argillaceous Media*	NEA No. 4437
2003	*Public Information, Consultation and Involvement in Radioactive Waste Management*	NEA No. 4430
2003	*The Regulator's Evolving Role and Image in Radioactive Waste Management*	NEA No. 4428
2003	*Geological Disposal: Building Confidence Using Multiple Lines of Evidence*	NEA No. 4309
2003	*Engineered Barrier Systems and the Safety of DGR*	NEA No. 3615
2002	"Safety Performance Indicators – Workshop Proceedings"	NEA/CSNI/R(2002)2
2002	*Establishing and Communicating Confidence in the Safety of DGR*	NEA No. 3628
2002	*The Use of Thermodynamic Databases in Performance Assessment. Workshop Proceedings, Barcelona, Spain, 29-30 May 2001.*	NEA No. 3055

Table A.1. General documentation *(cont'd)*

Year	Title	Publication ID
2001	"The Role of the Biosphere in a Safety Case"	NEA/RWM/IGSC(2002)2
2001	"Proceedings of the Clay Club Topical Session on Self-healing"	NEA/RWM/CLAYCLUB(2001)5
2001	*The Role of Underground Laboratories in Nuclear Waste Disposal Programmes*	NEA No. 3142
2001	*Scenario Development Methods and Practice*	NEA No. 3059
2001	*Regulatory Reviews of Assessments of Deep Geological Repositories*	NEA No. 2308
2001	*Using Thermodynamic Sorption Models for Guiding Radioelement Distribution Coefficient (Kd) Investigations*	
2000	*Features, Events and Processes (FEPs) for the Geologic Disposal of Radioactive Waste*	NEA No. 2549
2000	*Porewater Extraction from Argillaceous Rocks for Geochemical Characterisation*	NEA No. 2530
1999	*Confidence in the Long-term Safety of Deep Geological Repositories: Its Development and Communication*	NEA No. 1809
1998	*Fluid Flow through Faults and Fractures in Argillaceous Formations*	NEA No. 646
1997	*Lessons Learnt from Ten Performance Assessment Studies*	NEA No. 527
1996	*Water, Gas and Solute Movement through Argillaceous Media – A "Clay Club" Report*	NEA No. 139
In press	*Natural Analogue Workshop Proceedings*	-
In press	*Crushed Salt Compaction*	-

Table A.2. Thermodynamics database

Year	Title	Publication ID
2013	*Chemical Thermodynamics of Iron, Part 1*	CTS Vol. 13a
2012	*Chemical Thermodynamics of Tin*	CTS Vol. 12
2009	*Chemical Thermodynamics of Thorium (2009)*	CTS Vol. 11
2007	*Chemical Thermodynamics of Solid Solutions of Interest in Nuclear Waste Management*	CTS Vol. 10
2005	*Chemical Thermodynamics of Compounds and Complexes of U, Np, Pu, Am, Tc, Se, Ni and Zr with Selected Organic Ligands*	CTS Vol. 9
2005	*Chemical Thermodynamics of Zirconium*	CTS Vol. 8
2005	*Chemical Thermodynamics of Selenium*	CTS Vol. 7
2005	*Chemical Thermodynamics of Nickel*	CTS Vol. 6
2003	*Update on the Chemical Thermodynamics of Uranium, Neptunium, Plutonium, Americium and Technetium*	CTS Vol. 5
2001	*Chemical Thermodynamics of Neptunium and Plutonium*	CTS Vol. 4
1999	*Chemical Thermodynamics of Technetium*	CTS Vol. 3
1995	*Chemical Thermodynamics of Americium*	CTS Vol. 2
1992	*Chemical Thermodynamics of Uranium*	CTS Vol. 1

CTS – *Chemical Thermodynamics Series.*

Appendix B. List of EC documents on safety cases

Table B.1. EC funded projects in Framework Programme 6 and 7 (2006-2014) and networks

Project acronym	Project website
ACTINET-6 and I3	www.actinet-i3.eu/index.php?option=com_content&view=article&id=44 www.argonaproject.eu/argona-end-users-conference.php
ARGONA	www.skb.se/lagerbladet_33716.aspx
BELBaR	www.skb.se/belbar
BIOCLIM	www.andra.fr/bioclim
CARBOWASTE	www.carbowaste.eu
CARD	http://cordis.europa.eu/project/rcn/80060_en.html
CAST	http://cordis.europa.eu/project/rcn/110253_en.html
CATCLAY	http://catclay.org
CATT	http://cordis.europa.eu/project/rcn/78635_en.html
CIP	www.cowam.com/?-Cowam-in-practice-
COWAM-2	www.cowam.com/?COWAM-2-Final-Reports
CROCK	www.crockproject.eu
DOPAS	www.posiva.fi/dopas
EPIC	https://wiki.ceh.ac.uk/display/rpemain/EPIC
ERICA	https://wiki.ceh.ac.uk/display/rpemain/ERICA
ESDRED	www.esdred.info
FASSET	https://wiki.ceh.ac.uk/display/rpemain/FASSET
FIRST-NUCLIDES	www.firstnuclides.eu
FORGE	www.bgs.ac.uk/forge
FUNMIG	http://cordis.europa.eu/project/rcn/74124_en.html
IGD-TP	http://igdtp.eu
INSOTEC	www.insotec.eu
IPPA	www.ippaproject.eu
LUCOEX	www.lucoex.eu/index.html
MICADO	http://micado.wikispaces.com
MoDeRn	www.modern-fp7.eu
NF-PRO	http://cordis.europa.eu/publication/rcn/9702_en.html
OBRA	http://cordis.europa.eu/project/rcn/98367_en.html
PAMINA	www.ip-pamina.eu

Table B.1. EC funded projects in Framework Programme 6 and 7 (2006-2014) and networks *(cont'd)*

Project acronym	Project website
PEBS	www.pebs-eu.de/pebs/en/home/pebs_node_en.html
PETRUS I, II and III	http://cordis.europa.eu/project/rcn/93518_en.html
PROTECT	https://wiki.ceh.ac.uk/display/rpemain/protect
RECOSY	www.recosy.eu
REDUPP	www.skb.se/lagerbladet_31780.aspx
SAPIERR -I and II	www.erdo-wg.eu/SAPIERR_2.html
SITEX	http://cordis.europa.eu/projects/rcn/101495_en.html
SKIN	www.emn.fr/z-subatech/skin/index.php/main_page
THERESA	http://researchprojects.kth.se/index.php/kb_1/io_10152/io.html
TIMODAZ	www.timodaz.eu

Table B.2. EU directives and other non-project publications

Year	Title
2014	Council Directive 2014/87/Euratom of 8 July 2014 amending Directive 2009/71/Euratom establishing a Community framework for the nuclear safety of nuclear installations.
2013	Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom.
2011	Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste.
2009	Council Directive 2009/71/Euratom of 25 June 2009 establishing a Community framework for the nuclear safety of nuclear installations.
2006	Council Directive 2006/117/Euratom of 20 November 2006 on the supervision and control of shipments of radioactive waste and spent fuel.
2003	Council Directive 2003/122/Euratom of 22 December 2003 on the control of high-activity sealed radioactive sources and orphan sources. [*repealed by 2013/59/Euratom*]
1996	Council Directive 96/29/Euratom of 13 May 1996 establishing basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation. [*repealed by 2013/59/Euratom*]
2009	Falck, W.E. and K-F. Nilsson (2009), Geological Disposal of Radioactive Waste: Moving Towards Implementation, JRC Reference Reports, ISBN 978-92-79-12697-0, EC, Brussels.

Appendix C. List of IAEA documents on safety cases

Table C.1. IAEA Safety Standards Series

Year	Title	IAEA ID	Alt. ID
2015	*Monitoring and Surveillance of Radioactive Waste Disposal Facilities*	DPP 357	_ _
2013	*The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste*	GSG-3	Pub 1576
2012	*The Safety Case and Safety Assessment for the Disposal of Radioactive Waste*	SSG-23	Pub 1553
2012	*Regulations for the Safe Transport of Radioactive Material, 2012 Edition*	SSR-6	Pub 1570
2011	*Geological Disposal Facilities for Radioactive Waste*	SSG-14	Pub 1483
2011	*Disposal of Radioactive Waste*	SSR-5	Pub 1449
2009	*Safety Assessment for Facilities and Activities*	GSR-4	Pub 1375
2009	*Borehole Disposal Facilities for Radioactive Waste: Specific Safety Guide*	SSG-1	Pub 1418
2009	*Compliance Assurance for the Safe Transport of Radioactive Material*	TS-G-1.5	Pub 1361
2008	*The Management System for the Disposal of Radioactive Waste*	GS-G-3.4	Pub 1330
2006	*Fundamental Safety Principles*	SF-1	Pub 1273
2005	*Environmental and Source Monitoring for Purposes of Radiation Protection*	RS-G-1.8	Pub 1216
1999	*Occupational Radiation Protection*	RS-G-1.1	Pub 1081
1999	*Assessment of Occupational Exposure Due to Intakes of Radionuclides*	RS-G-1.2	Pub 1077
1999	*Assessment of Occupational Exposure Due to External Sources of Radiation*	RS-G-1.3	Pub 1076

Table C.2. IAEA TECDOC reports

Year	Title	IAEA ID
2014	*Cementitious Materials in Safety Cases for Geological Repositories for Radioactive Waste: Role, Evolution and Interactions*	TECDOC-1732
2013	*The Use of Numerical Models in Support of Site Characterization and Performance Assessment Studies of Geological Repositories*	TECDOC-1717
2013	"Guidance for Preparation of a Safety Case for a Dual Purpose Cask Containing Spent Fuel" (Draft report of WASSC/TRANSSC joint working group 2011-2013)	TECDOC-DRAFT
2012	*Review of Sealed Source Designs and Manufacturing Techniques Affecting Disused Source Management*	TECDOC-1690
2010	*Progress in Radioactive Graphite Waste Management*	TECDOC-1647
2006	*Characterization, Treatment and Conditioning of Radioactive Graphite from Decommissioning of Nuclear Reactors*	TECDOC-1521

Table C.2. IAEA TECDOC reports *(cont'd)*

Year	Title	IAEA ID
2005	*Natural activity Concentrations and Fluxes as Indicators for the Safety Assessment of Radioactive Waste Disposal*	TECDOC-1464
2003	Safety Indicators for the Safety Assessment of Radioactive Waste Disposal	TECDOC-1372
2001	*Monitoring with Respect to the Geological Disposal for High Level Waste*	TECDOC-1208
2000	*Inspection and Verification of Waste Packages for Near Surface Disposal*	TECDOC-1129
1997	*Regulatory Decision Making in the Presence of Uncertainty in the Context of the Disposal of Long Lived Radioactive Wastes*	TECDOC-975
1994	*Safety Indicators in Different Time Frames for the Safety Assessment of Underground Radioactive Waste Repositories*	TECDOC-767

Table C.3. Other IAEA reports

Year	Title	IAEA ID	Alt. ID
2011	*The Management System for the Development of Disposal Facilities for Radioactive Waste*	NW-T-1.2	Pub 1496
2011	*Comparative Analysis of Methods and Tools for Nuclear Knowledge Preservation*	NG-T-6.7	Pub 1494
2009	*Determination and Use of Scaling Factors for Waste Characterization in Nuclear Power Plants*	NW-T-1.18	Pub 1363
2009	*Geological Disposal of Radioactive Waste: Technological Implications for Retrievability*	NW-T-1.19	Pub 1378
2004	*Predisposal Management of Organic Radioactive Waste*	TRS-427	-
2003	*"Reference Biospheres" for Solid Radioactive Waste Disposal: Report of BIOMASS Theme 1 of the Biosphere Modelling and Assessment (BIOMASS) Programme*	BIOMASS-6	-
2003	*Scientific and Technical Basis for the Geological Disposal of Radioactive Wastes*	TRS-413	-

Table C.4. IAEA, in preparation

IAEA ID	Title
DPP 365	Risk-Informed Decision Making
DPP 425	Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material
DPP 453	Occupational Radiation Protection
DPP 469	Planning and Preparing for Response to Transport Events Involving Radioactive Material

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Sourcebook of International Activities Related to the Development of Safety Cases for Deep Geological Repositories

All national radioactive waste management authorities recognise today that a robust safety case is essential in developing disposal facilities for radioactive waste. To improve the robustness of the safety case for the development of a deep geological repository, a wide variety of activities have been carried out by national programmes and international organisations over the past years. The Nuclear Energy Agency, since first introducing the modern concept of the "safety case", has continued to monitor major developments in safety case activities at the international level. This Sourcebook summarises the activities being undertaken by the Nuclear Energy Agency, the European Commission and the International Atomic Energy Agency concerning the safety case for the operational and post-closure phases of geological repositories for radioactive waste that ranges from low-level to high-level waste and for spent fuel. In doing so, it highlights important differences in focus among the three organisations.

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